# ENGINEERING ECONOMICS

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# ENGINEERING ECONOMICS

*A Series of Lectures Delivered Before the Students of the University of Kansas, School of Engineering*

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In Three Parts:

I. THE GENERAL PROBLEM
II. ECONOMICS OF BRIDGES
III. ECONOMICS OF OTHER ENGINEERING SPECIALTIES

# ENGINEERING ECONOMICS

## LECTURE I

The subject of these lectures was not chosen by the speaker, but was allotted to him by your worthy dean of engineering, Prof. P. F. Walker. It is a topic that very few engineers would care to undertake to cover in three short lectures, not only because of its complication but also on account of its vast extent, permeating, as it does, every branch and division of engineering, great and small, and all work that is either directly or indirectly connected with the profession. On that account the speaker debated for some time before accepting the invitation to address you on the specified theme; for he would greatly have preferred to take some subject in which he has really specialized, primarily because he could do himself more credit thereby, but, it must be confessed, also because he rather dreaded the immense amount of preliminary study and research requisite to a proper presentation of the matter. As far as his specialty of bridges is concerned, he is able to treat the question of economics quite readily, because he has been dealing with it and writing about it for more than three decades; but when it comes to discussing economics in other lines of engineering, he feels very much at sea—so much so that he immediately decided that he would have to divide his discourse under two main headings,—viz., general features which pertain to engineering of all kinds, and detailed features relating to the numerous specialties into which during the last half century the profession has been segregated, and also that he would have to seek assistance on the latter. Any engineer of years and wide experience in one or more lines of activity should be capable of handling the first division, but no man, unaided, could adequately treat the second division in more than two or three specialties.

Recognizing this to be the case, the speaker took the liberty of calling to his aid some of the leading specialists and authorities of America so as to supply him with the salient features of economics in design and construction in the numerous divisions and subdivisions of engineering practice. Acknowledgment of such aid received is made throughout the text of these addresses, usually by means of foot-notes; but the speaker deems it advisable to state collectively at the outset the names of the gentlemen who have so favored him and their special lines of work. They are as follows, the arrangement of the list being alphabetical in relation to the specialties:

| SPECIALTY | AUTHORITY |
|---|---|
| City Planning | CHAS. MULFORD ROBINSON |
| Dams | ALFRED D. FLINN |
| Electric Railways | E. P. ROBERTS |

| SPECIALTY | AUTHORITY |
|---|---|
| Engineering Teaching | GEO. F. SWAIN |
| Harbors | WM. P. ANDERSON |
| Highways | W. G. HARGER |
| Inspection | P. S. HILDRETH |
| Mining | JAS. W. MALCOLMSON |
| Railroading | ELLIOT HOLBROOK<br>FRED LAVIS |
| Sewerage | LEONARD METCALF<br>HARRISON P. EDDY |
| Water Supply | ALFRED D. FLINN |

To all these gentlemen, individually and collectively, the speaker desires herewith to tender his hearty thanks and deep appreciation. Without their valuable aid these lectures on the lines adopted would have been impossible.

It should be noted that the preceding list of subjects is by no means complete. It is limited by the responses from the "authorities" to the speaker's appeal for aid. On the whole, the profession has been very generous; and while there is evidently a lack of correlation and uniformity in the various treatments, this is unavoidable. Moreover, it should not be objectionable, indicating, as it does very clearly, the personal equations of the donors of the information, notwithstanding the fact that occasionally the speaker has taken the liberty of materially modifying the diction.

Again, the incompleteness of the list of subjects is not a blemish; because, if it had been made even approximately complete, there would not have been sufficient time in the set limit to discuss all the topics with adequate fullness.

In one sense the subject of economics in engineering is a new one, because it is only of late years that it has been given much attention by designers, builders, and technical writers; but as far as the speaker's task is concerned it may be said to be an old one, for the reason that the said subject has been systematically and elegantly treated by Prof. J. C. L. Fish, of Leland Stanford University, in his excellent little work, which bears the same title as that of these lectures,—viz., "Engineering Economics". Although that work covers the ground in a satisfactory manner, it will not be necessary for the speaker to crib from it; because the subject is such a broad one that it will bear treatment from more than one point of view.

As far as relates to engineering, the term "Economics" has been defined thus in the "Glossary of Terms" of the speaker's new book on "Bridge Engineering"*,—"The science of obtaining a desired result with the ultimate minimum expenditure of effort, money, or material". It is upon the basis of this definition that these lectures are predicated.

## GENERAL FEATURES OF ECONOMICS

When determining, from the standpoint of economy, which is the best

*J. A. L. Waddell, 1916, "Bridge Engineering", Wiley & Sons.

of a number of proposed constructions or machines, one should compute for each case the four following quantities, and their sums:

A. The annual expense for operation.
B. The average annual cost of repairs.
C. The average annual cost of renewals.
D. The annual interest on the money invested.

That one for which this sum is least is the most economic of all the proposed constructions or machines; but this statement is truly correct only when the costs of operation, repairs, and renewals are averaged over a long term of years; or else, for a comparatively short period of time, when the conditions in respect to wear and deterioration at the end of that period are practically the same for all cases.

The principal economic investigation that occurs in engineering practice is that of determining the financial excellence of a proposed enterprise. It consists in showing by proper calculations its first cost, the probable total annual expense of maintenance, repairs, operation, and interest, the advisable allowance for deterioration or ultimate replacement, the probable gross income, and the resulting net income that can be used in paying dividends on the stock or other profits to the promoters. Whether any proposed enterprise, after being thus figured, will prove profitable will depend greatly on the state of the money market, the size of the project, the probabilities of future changes in governing conditions, and the personal equation of the investor. Generally speaking, if the computed *net* annual profits on the total cost of the investment (over and above all expenses of every kind, including maintenance, repairs, operation, sinking fund, and interest on all borrowed capital) do not exceed five (5) per cent of the said total cost, the project is not attractive; if it be as high as ten (10) per cent, the enterprise is deemed ordinarily good; and if it be fifteen (15) per cent or more the scheme is termed "gilt-edged". Small projects necessitate greater probable percentages of net earnings than do large ones; and any possibility of a future reduction of income will call for a high estimate of net earning capacity. Finally, the measure of individual greed on the part of the investor will be found to be an important factor in the determination of the attractiveness of any suggested enterprise.

Such investigations as the economics of an important project should generally be entrusted only to engineers experienced in the line of activity to which the said project properly belongs; for if they be left to inexperienced investigators, it is more than likely that mistakes will be made and money lost in consequence. The professional men who generally do such work are the independent consulting engineers; certain specialists retained on salary solely for this purpose by important organizations, such as railroad companies; and engineers who are regularly in the employ of large banking houses. The work involved is of such importance that it usually commands large compensation—as, indeed, it should; because to do it effectively demands not only long experience but also good judgment and a vast amount of mental labor, both in order to make oneself capable in general and so as to consider thoroughly all the points embraced by the special problem in hand.

This fundamental economic problem is often one of extreme complication, involving, perhaps, a determination of the character of the proposed improvement, a choice of sites or routes, a selection of uses, a consideration of æsthetics, an option on type or style of construction, a question of ultimate durability, a study of greatest possible convenience, a prevision of serious opposition, a prognostication of future conditions, an anticipation of prospective structural modifications, and a safe estimate of cost. The best way to illustrate such complication is by presenting a few examples of actual cases, either pending or already solved; and in so doing the speaker hopes that he will be pardoned for selecting them mainly from his own specialty of bridgework and his own personal experience, because he can thus enter more fully into detail and can vouch for the information's being correct.

## CASE I

There is in contemplation a project for building a long, high, and exceedingly expensive bridge across San Francisco Harbor so as to connect the great city of San Francisco with the cities of Oakland, Berkeley, and its other suburbs. This project has been a dream for at least a decade; but it is not a pipe-dream, because some day in some manner or other it is certain to be realized. Some eight years ago the speaker prepared a report for a banker on the feasibility of the project, the necessity for the structure, the possible revenue from its use, and its approximate cost; and since then several other engineers have made independent studies of the problem. The communities interested, however, have taken as yet no sensible step towards making a thorough study of the question.

How short sighted most promoters of important projects can be! They imagine they can obtain expert opinion of real value without paying for it; consequently they collect a mass of scattered and divergent information, which, in most cases, is of no earthly use. Any project of importance is, of necessity, a great economic problem, and ought to be solved at the very outset by special engineering talent of the highest order.

A glaring example of the utter folly of a community in proceeding with important engineering construction without first having a thorough economic study of the problem made by a competent specialist is given in *Engineering News* of November 30, 1916. It relates to the municipal water-power enterprise on which the city of Montreal has been busy for some years. Feeling that the work was being sadly mismanaged, certain prominent Canadian engineers "butted in", investigated, and reported upon the incomplete project. They showed that the $12,000,000 enterprise which the city had about half finished will fall so far short of returning a profit on its cost, and that it has so many serious defects, that it will be far better for the community to lose all it has thus far expended than to incur the additional outlay necessary to complete the work. A thorough investigation to determine beforehand whether the scheme would be profitable would certainly have indicated the futility of constructing on the lines that were adopted.

But to return to the case of the proposed San Francisco Harbor bridge—practically none of the governing conditions are satisfactorily known; and, judging by present indications, it is likely to be a long time before they will be, unless, perchance, the leading citizens of the various communities concerned bestir themselves and prevail on their ruling bodies to join forces, raise the requisite funds, choose an engineer of national reputation (or, preferably, a board of three such engineers), arrange to allow him or them adequate compensation for expert services and all the money necessary for borings and other investigations, accord ample time for the entire work, and thus obtain a report that will settle finally all the important economic and technical points involved in the proposition.

The main features to determine are as follows, the listing being done according to relative importance:

FIRST. The probable gross incomes from all practicable combinations of the various sources, year by year for a long term of years, and the proportion thereof that is likely to prove net in each combination.

SECOND. Based upon the result of this investigation, the determination of the extreme superior limit of cost for the structure for each combination of the different kinds of traffic.

THIRD. In view of the great depths of water in the harbor, what one or more of the several proposed or possible sites might be utilized for building a bridge within the several ascertained limits of cost.

FOURTH. Of what kind of traffic it is advisable that the proposed bridge should take care.

FIFTH. The character of the foundation soil as determined beyond all doubt by making proper borings, and the settlement of best depths for all pier foundations.

SIXTH. The various requirements of the U. S. Government in respect to minimum span-lengths, vertical clearances, and temporary obstruction of waterway for each proposed crossing.

SEVENTH. The minimum clear headway which, for a combination of all reasons, it is expedient to adopt for each proposed crossing; and the choice between a bridge with and a bridge without an opening span or opening spans.

EIGHTH. A safe estimate of total cost of structure for each layout that proves to be feasible, and the corresponding estimates of cost of operation, maintenance, repairs, etc.

NINTH. The time required for completion of construction of the structure for each feasible layout.

After all these points have been settled and embodied in a report, it will be easy to determine finally whether, either at the present time or within a certain number of years, it will be feasible or advisable to build the proposed structure; where it should be located; what traffic it should carry; how long it will take to build it; what it will cost for construction, maintenance, and operation; and how the necessary funds are to be provided.

The actual conditions for the proposed San Francisco Harbor bridge, as well as they can be stated at present, are as follows:

A. There is a large possible income from passenger traffic, mainly from commutors who now use the ferry, most of which traffic would soon be diverted to the structure, provided that truly-rapid transit thereon be furnished at all times; and the said income, under present conditions, would be large enough to warrant the building of an open-decked, double-track, electric-railway bridge which would carry no other kind of traffic.

B. There is a rapidly increasing amount of automobile traffic now cared for by the ferry; and this, undoubtedly, would be augmented materially by the superior and, possibly, cheaper service of the bridge; nevertheless it is doubtful whether it would be large enough to warrant the building of separate passageways with paved floor and the necessarily greater carrying capacity of the trusses. It would be out of the question to let the automobiles use the same space as the electric trains; for such an arrangement would prevent the rapid transit of the latter.

C. There is an immense amount of freight crossing the water; but, for two reasons, it does not appear probable that it would ever be economical to transport it over a bridge. The first reason is the great height to which both it and its containing vehicles would have to be lifted, and the consequent expense of such lifting. The second is the greatly augmented cost of structure, due to the far larger live loads for both the floor system and the trusses, that the carrying of such freight would necessitate. It would probably be more economical either to transfer the freight by ferry as is done at present, or to carry it by rail around the south end of the Bay.

D. There is at certain seasons a large amount of passenger traffic to and from San Francisco by certain trans-continental railroads; hence the question arises whether the passengers should be carried across in the steam-railway cars on which they travel or whether they should go over in the electric-railway cars. The objection to the latter method is the individual trouble, inconvenience, and loss of time for each passenger; while the objection to the former is the increased cost of structure due to the difference in the live loads between steam-railway cars and electric-railway cars. Of course, the former would have to be hauled in short trains by electric motors so as to avoid the excessive concentrated loading from the heavy steam-locomotives.

E. The most direct route for the crossing is from Telegraph Hill to the outer end of Goat Island, and thence to near the Oakland Pier; and this is the one to which, until quite lately, most attention has been paid. The main objections to it are as follows:

FIRST. The depth of water between the city and Goat Island is excessive, thus making the pier foundations very expensive.

SECOND. A large proportion of the steamers using the harbor would have to pass under the structure.

THIRD. The War-Department requirements in respect to both horizontal and vertical clearances would be excessive for this location because of the large number of vessels passing; and, in consequence, the cost of structure would be greatly augmented.

F. By locating further inside the Bay, the depth of water would be reduced to a reasonable amount, and the number of vessels passing the structure would be comparatively small. In fact, the farther back from the harbor-entrance the structure is located, the smaller will be the depth of water and the fewer will be the passing vessels. On the other hand, though, the greater will be the total length of structure, the farther from the centre of population will be its city end, and the greater will be the distance which the passengers will have to travel.

G. Practically nothing is known about the characters of foundations that would be encountered at the various proposed locations; and no provision has been made for money to make the necessary borings.

H. It is impracticable to obtain a final decision concerning required span-lengths until a *bona fide* design, properly backed, has been presented to the War Department for approval.

I. In regard to minimum clear-headway, it is probable that the farther inside the harbor the location the less the requirement, because the smaller and less important would be the passing craft, and the fewer the number thereof. Some of them might be forced to lower topgallant masts in order to pass beneath the structure.

J. There would be a serious objection to any opening span because of the delay which would be involved by its operation. The real *raison d'etre* of the structure is rapid transit, hence to interfere with it in any way would be highly objectionable.

K. The total cost of structure would decrease to a certain point as the location is moved up the harbor, because of cheaper foundations and the consequently shorter spans; but beyond the said point it would increase because of the greater length of bridge.

L. The more expensive the structure the longer will be the time required to build it; hence it may be concluded that one of the inner harbor locations would need much less time for completion of bridge than the Goat-Island layout. This matter of time for completion of structure possesses a double importance, because any delay increases the item of cost due to interest during construction; and by postponing the inception of operation it involves a loss of income from use.

From the preceding it is evident that the solution of the initial economic problem in connection with the proposed San Francisco Harbor bridge is one of considerable complication.

## CASE II

The City of New Orleans for many years has had under consideration the building of a combined railway and highway bridge across the Mississippi River; and within the last year the project has been seriously contemplated.

Nearly two decades ago the late Collis P. Huntington, President of the Southern Pacific Railway Company, and his consulting engineer, the late Dr. Elmer L. Corthell, made an investigation of the scheme of building at that place a double-track railway bridge; and they called in as advisory engineers the speaker and his brother, Montgomery, to estimate upon the cost of a low bridge. The death of Mr. Huntington, which occurred shortly afterwards, caused the project to be dropped; and it was never revived. The speaker's study was made with considerable thoroughness. It involved the solution of two or three problems of great magnitude which were new to the engineering profession, the principal economic one being a comparison of costs of a high bridge and a low bridge. The result was decidedly in favor of the latter.

The problem now facing the City, however, is much more complicated, involving, as it does, a combination of steam-railway, electric-railway, vehicular, and pedestrian traffics. There is a choice between two locations, one near the centre of the city and the other several miles further up-stream—in fact, some intermediate locations might have to be considered. There is a sentiment among certain prominent citizens favoring a tunnel rather than a bridge; and, on that account, the question of bridge *versus* tunnel will have to be considered, notwithstanding the fact that the difficulties presented by the tunnel proposition are almost insurmountable in view of the present status of engineering knowledge and experience.

The question of high-bridge *versus* low-bridge will have to be thoroughly thrashed out in order to please the populace, although any truly-experienced engineer would determine very quickly in favor of the latter, irrespective of the possible opposition of the river interests and even that of the War Department.

The economic method of handling the combination of the various kinds of traffic would require some study to determine; and the best method might vary with the location of the structure.

The style and dimensions of the moving span—whether swing, bascule, or vertical lift—and the sizes of the clear opening or openings are mooted points involving a consideration of economics and other important matters. This question is complicated by the fact that the requirements ought to be dependent on the location; because at the upper one there would be very few vessels passing, while at the lower one there would be many.

The unprecedented depth for the pier foundations involves an economic study in order to ascertain the best method of sinking and founding.

The facilities for freight, passenger, and vehicular traffic afforded by the several proposed crossings would affect the total earnings of the structure; hence this feature should receive special attention.

The grade and alignment for any proposed crossing are factors that must be included in the economic study, because they affect the cost of handling the traffic; and the matter of right-of-way may prove an important consideration.

The property damages involved by the approaches to the structure and the shifting of existing tracks would differ materially in cost at the various possible crossings, hence this feature is one involving economics.

The choice between single-deck and double-deck spans entails a consideration of economics that may prove to be of some importance.

After determining the various kinds of traffic to take care of, there remains the economic problem of deciding upon the live loads for the various parts of the structure. If these are made too high, there is a waste of material involved, and the bridge enterprise will forever after be burdened with an unnecessarily large annual interest to be paid on that account; but if they are made much too low, the life of the structure will be curtailed. The saving clause, however, in respect to this adjustment is that, ordinarily, a steel bridge does not have to be removed because of overloading until the metal thereof is actually stressed at least fifty (50) per cent more than the permissible intensities of working stresses given in standard specifications for design.

This general problem of the proposed New Orleans bridge, while not so complicated as that of the proposed San Francisco-Harbor structure, is of an intricate nature, and will demand for its solution engineering ability and experience of the highest order.

## CASE III

There is given in the speaker's treatise on "Bridge Engineering" in the chapter on "Reports", on pp. 1575 to 1581, inclusive, an economic study for the replacement of a bridge over the Mississippi River, which illustrates some of the economic questions that arise in a consulting bridge engineer's practice. In that case the point at issue was whether it would be best to build a single-track or a double-track bridge or to arrange for the conversion at some future time of a single-track structure into a double-track one. Five methods of doing the latter were suggested, and the estimates of their total first cost were made; then, at an assumed rate of interest, a table was prepared showing the total cost of each structure plus interest thereon for periods of five years, up to the limit of forty years. That table indicates at a glance the comparative economics of all five methods at any of the five-year periods. A diagram prepared from the said table, of course, would be preferable, as it would show more readily the comparison at any intermediate period.

## CASE IV

As stated by Lavis, "The application of economics to railroad location and construction consists in the proper adjustment and balance between the first cost as exemplified by the straight line of uniform rate of gradient and the first cost of a line or a series of lines which deviates from it in more or less degree, and the difference in cost of operation due to this deviation (whether lateral or vertical), and the consequent introduction of added resistance and, therefore, added cost of operation". In railroad engineering there are, certainly, quite complicated preliminary economic problems to solve, among which may be mentioned the following:

A. A location of the road which will ensure that the net earnings shall be as large as possible; and to do this it will be necessary to run the line to or through all important traffic-points which can reasonably be reached.

B. An adjustment between the character of the construction and the probable gross income from traffic. If the latter be large, it will pay to build a first-class road with heavy rails, light grades, easy curves, comparatively expensive station buildings, and permanent structures; but if it be small, the original rails may be light, the grades comparatively heavy, the curves rather sharp, the station buildings cheap, and the structures temporary.

C. An adjustment between the total length of line between termini and the amount of money available for construction. Under ordinary conditions and within certain limits, a railway line can often be cheapened by lengthening it. This, of course, is done by increasing the total amount of curvature, and, consequently, the cost of operation. Holbrook states that for each degree of curvature there is an added train-resistance equivalent to a lift of four or five hundredths of a foot, so that a complete circular curvature is equivalent to a lift of about sixteen feet, or to a haul of one mile on straight, level track. The energy required to overcome the resistance to curvature is furnished by the engine; and the work performed by the said energy is the destruction of both the equipment and the track. It is difficult to determine the amount of wear of wheels due to curvature, as apart from that due to straight line; but it is not so difficult to locate the extra wear on the rails. From the investigations which have been made on this subject, it has been found that the cost of repairs for the damage done is as great as the cost of the energy expended by the engine in doing it, so that the total cost of curvature, from an operating standpoint, is at least twice as great as the cost of the energy necessary to overcome the added resistance due thereto.

Apropos of rail-wear, it is pertinent to call attention to the ultra-conservatism of most American railroad authorities in adhering to the use of rails that have their webs perpendicular to the upper faces of the ties instead of perpendicular to the coned faces of the wheels. This divergence from the normal, which is only one in twenty, can best be secured by using beveled tie-plates. The effect of it on tangent is to reduce the rotating bending-moment on the rail to zero and to bring the wear on both rails and wheels to a minimum, also to make the said wear regular, uniform, and parallel to the top normal plane of the rails and to the coned surfaces of the wheels. In turn, this effect makes the trucks ride more easily and smoothly, and thus reduces the rack on the locomotives and cars.

Again, many railroad officials object to the widening of gauge on curves, in spite of the glaringly-evident fact that, unless this be done, the rigid trucks will cause the wheels to grind against the inner faces of the rail-heads. The necessity for this widening is so obvious that the speaker cannot comprehend the obstinacy of any railroad man in adhering to the maintenance of a constant gauge for both tangents and curves. Nor can he appreciate the reasoning of those who refuse to incline the rail-webs so as to be normal to the wheel-coning. Both of these changes in American current practice are so obviously beneficial that any scientifically-thinking man must concede their desirability.

Returning to the matter of curvature, there are other somewhat intangible factors which enter into its cost-effect—principally those due to the limited field of view on curves. An examination into the cause of wrecks and of injury and death to trackmen and others on the track discloses the fact that most of these would not have happened, had there not been a curve in the vicinity. The extra strain upon the track and the equipment due to curves also leads to accidents which would not otherwise occur.

It is evident, therefore, that this particular economic problem involves not merely first-cost of construction but also cost of operation.

D. A proper determination of the ruling grade in reference to both the present and the prospective traffic. By reducing the ruling grade we make it possible to handle heavier trains; and, therefore, fewer trains are necessary. This results in a saving (possibly a very large one) in the operating expenses.

E. An adjustment between the total rise and fall of grades and the first cost of grading. Of course, the maximum height to be surmounted can very seldom be controlled to any appreciable extent, unless resort be made to tunnelling in the vicinity of the summit; but the minor apices and depressions can be reduced by increasing the quantities in the cuts and fills. As in the last case, this economic feature is by no means one of first cost only, because the total amount of rise and the cost of energy expended increase and decrease together. Although it is true that some of the energy stored in the train on a down grade can be utilized for climbing the next rise, the amount thereof is generally small.

F. The time allowed for completing the road. This is always an economic feature because of the question of interest during construction. The longer the time required to finish the line and to put it in operation the greater will be the amount of the interest on the capital borrowed to pay for construction; consequently it will sometimes be truly economical to expend extra money on first cost in order to shorten the time for completion. There is another economic feature that is sometimes involved by the time element, and which often becomes temporarily of paramount importance,—viz., the offering by communities of large bonuses in cash or realty for the finishing of the road so as to bring trains to certain places at or before certain times. Under such conditions, it often happens, and very properly too, that every nerve is stressed to the highest tension in order to accomplish the desired purpose, regardless of the amount of expenditure of money and effort.

## CASE V

In 1914 there was prepared (but never published) by Robert C. Barnett, Esq., consulting engineer, and now associate engineer in the speaker's firm, a paper entitled "A Comprehensive Policy for River Improvement". This essay is a masterpiece of engineering economics; and as it relates to generalities rather than to details, it is reproduced here nearly verbatim, as follows, with the kind permission of its writer:

The need for a broad, comprehensive policy in dealing with our rivers is again forced home on us by the recent reports of the Army Engineers, the Geological Survey, and several private engineering firms. These reports, emanating from different sources and inspired by different view points, serve to emphasize the existing lack of correlation of purpose, of coördination of plan, of coöperation in execution.

We have today various separated and unrelated organizations striving to promote some form or other of river improvement. For example, there are the Board of Army Engineers, the National Rivers and Harbors Congress, the Geological Survey, the Mississippi River Commission, the Mississippi River Levee Association, the National Drainage Congress, the Interstate Levee Association, and others. There is no correlation of purpose—no coördination of effort; but each organization is seeing only its own special problem and is overlooking the big fundamental problem underlying the whole subject. There is so much at stake, so many interests are affected, such large investments are called for, such far reaching economic benefits are possible, that it is well worth our while to pause and consider what this fundamental problem is. By such consideration we shall come to a better realization of what we might attain; of the inadequacy of our present system and methods; of the inefficiency of the many detached and unrelated organizations now promoting river improvements; and of the great need for a policy broad enough, fundamental enough, to enable us to accomplish a permanent solution.

Such a policy must be based on sound economics; for the general problem is essentially an economic one. What economic principle should form the basis of such a policy? Let us consider a little more in detail, and perhaps in an elementary way, the first principles involved.

The economic problem underlying the improvement of our streams and rivers is a most fundamental one. It is but a phase of the general economic problem which confronts mankind. This problem reduced to its lowest terms is that of satisfying human wants. A very large part of our activities has this fundamental object in view. Obviously, we are directly and seriously concerned with the satisfying of the maximum amount of want—not only the maximum amount of individual want, but of collective want; for the interests of the individual are so inter-related, inter-laced, and connected, so dove-tailed into each other, that the individual's maximum does not obtain until the maximum for the social organism obtains. This is a prerequisite for economic equilibrium.

Should our efforts fall short of producing this maximum satisfaction, there remains an unattained potential increment. This unattained increment, measured by the difference between possible attainment and actual attainment, is an incentive for further effort in the future to disturb conditions, to re-arrange relations, to re-adjust conflicting interests. Such disturbance, such re-arrangement, such re-adjustment means an undoing of the things we are doing today, a throwing away of improvements made yesterday, a backing up and taking a fresh start, a wasting of time and of resources. Such an unattained increment produces a corresponding incentive which is a continuous and persistent menace to our stability. It, therefore, behooves us, while formulating a policy for any development, to take into consideration the kind and the amount of development which will ultimately produce this maximum satisfaction. Previous failure to recognize this principle is today causing us to undo, or to do over, the things of yesterday. Had yesterday's planning been done on a broader, a more comprehensive, a more fundamental basis, today's efforts would have been in harmony therewith; and, instead of tearing out and replacing, we should simply have to add to our former achievements, and thereby get the benefit of a cumulative process of development. It is this fundamental principle of producing a maximum satisfaction, or its correlative maximum utility, that we should bear in mind when approaching the problem of establishing a general policy for the improvement of our rivers and streams.

What is this maximum utility which can be produced by river improvement? If we are to formulate a policy based on maximum utility, we must have some conception of what that maximum utility is and how it may be obtained. Heretofore, we have been prone to regard our rivers as available only for one or two purposes. One such purpose, discovered early in the career of mankind, is that of navigation. This continued along for years, until navigation, which originally was a mere incident, has come to be regarded as the sole and primary purpose of our rivers and streams. To such an extent has this view obsessed the minds of our legislative bodies and the official heads of departments that, until recently, little or no regard has been given to the other possible uses to which our river systems can be put. Note, for instance, how the War Department through the Army Engineers has considered navigation to be the paramount utility. These engineers have, in most cases, confined their work to improvement of the channel solely for navigation purposes, ignoring the adjacent flood plains and their need for protection. Note also how the power development at Keokuk was penalized to the extent of $2,000,000 in order to construct a lock, a dry dock, buildings, and other improvements, while at the same time the benefit to navigation rendered by such power installation is said by river men to be worth at least $5,000,000.

THE PRIMARY AND FUNDAMENTAL PURPOSE OF OUR RIVERS AND STREAMS IS THAT OF DRAINING THE WATERSHEDS. This purpose obtained long before the advent of man, and still continues to be the essential function. Therefore, our first consideration should be to increase the efficiency of these drainage channels for their respective watersheds. Hence our comprehensive policy should start from this basis. To increase the efficiency of a drainage channel is an engineering problem; and hence it will not be considered further at this time. We might note in passing that it will be found that in planning for an increased efficiency of drainage channel, we may obtain other incidental but very desirable results, including an augmented discharge capacity.

As the country becomes settled and land values augment because of the increasing density of population and the production of wealth, the protection of river lands and of the property and lives of the people living thereon becomes a matter of great importance. The erosion of these rich, fertile, bottom lands, the destruction of crops and other property, the jeopardizing of human life and often the loss thereof, all contribute to a far-reaching loss which becomes a burden to the rest of the country as well as to the afflicted districts; hence our comprehensive policy should recognize this very important element of the general problem. How to secure flood protection is purely an engineering question, and will be passed over for the present.

The need for transportation becomes more urgent as the country settles up and as population concentrates at certain points. Water transportation is more economic for certain classes of freight than rail transportation, hence it is to the general interest of the country to facilitate the former, consequently the navigability of our rivers should receive consideration in our comprehensive policy. How to improve navigation is another engineering problem; and, as such, it will be passed over for the present.

As the river towns expand into large cities, the need for a municipal water supply becomes of corresponding importance, and, hence, should receive attention in the formulation of our comprehensive policy. The securing of a water supply is likewise an engineering problem.

In certain arid and semi-arid sections of the country the needs of irrigation are paramount; and, as a matter of fact, in other sections favored ordinarily with abundant rainfall there may come a drought at the critical growing time, so that irrigation is much needed even there. Hence our comprehensive policy must recognize the demand for irrigation. How to provide and divert water for irrigation is also an engineering problem.

The development of the country's resources is making a larger and larger demand for cheap power. Statistics show that the utilization of power has increased from 2,346,142 H. P. in 1870 to 14,641,544 H. P. in 1905. This shows an increase in the per capita consumption of from 0.060 H. P. to 0.177 H. P. We must be prepared for an increasing number of power installations to meet the growing demands of an increasing population and an increasing per capita consumption. Many of our rivers and streams have power possibilities; and the utilization of these is of the greatest economic concern to the entire country, hence our comprehensive policy should provide encouragement for water power development. The actual planning for power and the development thereof from our rivers and streams constitute an engineering problem; and, therefore, will be passed over for future consideration.

From the foregoing, we see that a comprehensive policy for river development seeking to obtain the maximum utility should provide for the following:

(a). An efficient drainage channel and an increased discharge capacity.

(b). Protection from floods, together with reclamation of low lands, drainage, and prevention of erosion.

(c). Improved navigation facilities.

(d). Municipal water supply and incidental storage of flood waters.

(e). Irrigation, with its incident diversion-canals and its storage of flood waters.

(f). Water power development and its storage of flood waters.

While it is recognized that each stream presents its own special problem and requires a specific solution to meet actual conditions, yet it is readily seen that should we fail to plan for the ultimate development of all its utilities, we fall short by that much of reaching a maximum. Likewise, if we develop one utility at the expense of another, we fail to reach the maximum. What is needed is a plan or program that will permit of a balanced development. A comprehensive policy embracing these features will make it possible in many cases to obtain a number of them with one investment.

For example, if it be desired to provide a more efficient drainage channel in order to discharge floods for some watershed, it may be found possible to provide at the same time levees that will protect the lowlands from overflow and also give an increased efficiency to the channel. The matter of bank protection and the prevention of erosion could be taken care of in the same improvement. By the careful selection of a suitable channel-cross-section and the maintenance thereof, navigation facilities could be improved during low water, and yet at high water the discharge capacity of the channel would not be interfered with. If at the same time our plan of development include diversion canals and storage reservoirs, we can relieve somewhat the peak of the flood-flow while storing up water for irrigation, municipal supply, or power purposes. Such an adjustment of related interests and conditions could be obtained that a maximum utility would result.

In contrast with this, consider some of the actual conditions confronting us today. We find cases where levees have been built for flood protection to the detriment of the channel. That is the levees on opposite sides of the river approach and recede from each other over a wide range, thereby forming an irregularly varying channel-cross-section of changing area and differing hydraulic radius with a consequent variation in velocity, so that, during floods, silt is being picked up at one stretch of the river and deposited in another; and we get the effect in places of raising the river bed above the elevation of the adjoining bottom lands. We find cases where dams and locks have been built to improve navigation but no attempt has been made to utilize the resulting head for power development.

Again, consider the case of a constructively navigable stream that will hardly float a motor boat a large part of the year and yet is rich in power possibilities. Under our comprehensive policy, power development would be encouraged. The building of one or more dams would provide slack-water navigation for certain reaches, while at the same time storing water for power purposes. The storage of flood waters and their subsequent gradual release through the power plant would equalize the flow below the dam so that navigation would be greatly benefited thereby. The development of cheap power would bring in its wake more industries, more population, more need for water transportation, and a great building up of the community, all of which leads towards the production of maximum utility.

Other examples could readily be cited; but it is believed that enough has been said to show the possibilities to be obtained by the formulation of a comprehensive policy and to indicate the economic basis upon which such a policy should rest.

However, the excessive floods of last spring have forced home the urgent need for protection; and in our anxiety to provide such protection we are apt to overlook the fact that the protection problem is but a phase of a larger and more fundamental problem. Unless this fundamental problem of obtaining the maximum utility is kept before the minds of our legislators and departmental heads, we are apt to get only a partial solution of it because of the desire to provide immediate protection and relief. The investment that we may now make for partial relief will very likely have to be discarded later on, unless it is made with the view of fitting into the final development. It would be better and, in the long run, more economical to conform to a comprehensive plan looking toward ultimate development, even though it take years to carry out such a program. We should have a very material advantage in pursuing a definite general policy, such that the work done in the early period of development would not have to be undone at some later stage and a costly investment discarded.

Under a general comprehensive policy, our work could be planned in such a way that we should continually be building up and strengthening all investments and improvements. The desirability and efficiency of such a policy must be recognized by all students of the situation.

How to impress the great need of such a policy on the minds of our public men, legislators, and officials of various departments, on various state and local organizations now aiming at some one detail in improvement, is the serious question.

It has been seen that each feature to be covered by the general comprehensive policy required for its attainment involves the solution of an engineering problem. This being the case, the formulation of such a general comprehensive policy could best be done by engineers who are experts in the several lines involved. It is here that our National Engineering Societies could perform a service for the country in general and for the profession at large by appointing a joint committee to outline such a policy and a tentative program for securing its adoption and execution. After the joint committee had recommended for adoption a comprehensive policy embracing the idea of a balanced development of our river systems so that a maximum utility would result, local engineering societies and individual engineers could well assist the National Societies by taking up the work of presenting such a policy to their respective congressmen.

As the primary purpose of this communication is to emphasize the need for a comprehensive policy and to impress on the minds of all engineers the importance of the engineering profession's taking a hand in formulating such a policy and in outlining a skeleton program, the writer will only attempt at this time to mention briefly some salient features thereof, leaving for a future article the presentation of a more developed program. It is believed that the salient features of such a preliminary program should be the following:

An act of Congress adopting the comprehensive policy, to be recommended by the Joint Committee of the National Engineering Societies, and providing for a Coördinating Board of Engineers, the manner of selecting them, and their compensation.

The coöperation of the States with the National Government.

A division of affected territory based on watersheds of convenient size.

The appointment by each interested State of a State Board of Engineers for this particular work, and to provide for their compensation by the State.

Each State Board to work out tentative plans for developing the utilities of its own rivers and streams.

Where a watershed embraces more than one state, the several State Boards interested to select from their own membership a member of the Watershed Board, so that each State would be represented on the said Watershed Board.

The Watershed Board to harmonize the plans of the several State Boards under it.

The various Watershed Boards to meet with the Board of Army Engineers and Federal authorities from time to time and coöperate in perfecting plans.

The various Watershed Boards, the Board of Army Engineers, and the Federal authorities to select an even number of members to form the Coördinating Board of Engineers, as provided by act of Congress. These members in turn to select from the country at large an additional odd number of engineers to complete this Board.

The purpose of the Coördinating Board should be to perfect the details of the program for carrying out the purposes of the general comprehensive policy, to harmonize general plans for execution, and to apportion the expense of any improvement to those interests receiving the benefit of such improvement, whether these be individuals, cities, counties, states, or the general government.

While all this seems like a very large undertaking, yet the benefits to be derived by it are of the same magnitude; and they will eventually justify such a program and the investments made in accordance therewith.

The general features of economics in respect to the inception and financing of engineering projects have now been described at some length for bridges, railroads, and river improvement; and this treatment of the subject should suffice for an example of how to handle the preliminary economic questions in all other lines of technical activity.

We can now pass to the second division of these lectures,—viz., the economics of design and construction; and in so doing it is practicable to enter much more into detail than we have previously; but before dealing with certain of the numerous specialties into which engineering is divided, we shall touch lightly upon a few general matters pertaining to the economics thereof.

### *Anticipating The Future*

In all engineering work of both designing and construction, true economy necessitates a thorough consideration of future requirements and possible eventualities, also a provision for meeting the same. For instance, in designing a structure one should consider possible future additions of loading and how to accommodate them; and in construction one should anticipate delays, floods, storms, and other possible difficulties, and should prepare his programme so as to meet them effectively and without any unnecessary expenditure of time, labor, or money. Foresight of this kind is an important element of success in the career of every engineer.

### *Systemization*

Quoting from the speaker's treatise on "Bridge Engineering", "The systemization of all that one does in connection with his professional work is one of the most important steps that can be taken towards the attainment of success". Moreover, it is one of the fundamental elements of economics in all lines of work.

### *Time Versus Material*

Some designers in their endeavor to save a small amount of material expend a large amount of time, not only of their own but also of other people's, which time when properly evaluated is often greatly in excess of the cost of the material saved. Such economy as this is false; and its practice is unscientific.

### *Labor Versus Material*

Similarly some designers in an endeavor to cut down quantities in their structures increase the labor thereon to such an extent that the material saved is worth only a small portion of the value of the extra labor expended. For instance, if one were to make a small pier hollow, the concrete thus saved would not be worth anything like as much as the cost of the forms required to construct the hollow space.

### *Recording Diagrams*

The study of economics is greatly facilitated by the use of diagrams that record quantities of materials, costs of construction, times of operation, etc., for varying conditions. In general, it may be stated that American engineers do not use graphics for studying economics to the extent which is advisable; and that in this they might learn something from their European brethren.

### *Economics of Mental Effort*

Almost nothing concerning this important subject is taught in our technical schools; and but little is known about it by practicing engineers. To be a truly successful engineer, one has need to study deeply the matter of how best and most economically to utilize his mental forces; how to accomplish the greatest amount of work with the smallest expenditure of effort; how many hours of work per day for long-continued labor will effect the largest accomplishment; to what extent men in various lines of activity should take vacations, and how these should be spent; what are the effects upon one's working capacity from the use of liquor and tobacco in both small and large quantities; etc. All these are ecomonic questions of great importance; and they need to be given proper attention by every engineer who aspires to efficiency in both himself and his employees.

Again, the development of the faculty of concentration is an economic consideration of much importance.

### *Economics In Office Practice*

There are many conditions in ordinary office practice that are susceptible of considerable improvement from the economic point of view—for instance, unnecessary conversation, useless duplication of labor, and lack of proper checking; but this matter is too complicated and lengthy to warrant more than mere mention in a lecture of this kind. The subject will be found very thoroughly treated in Chapter LVIII of the before-mentioned treatise on "Bridge Engineering".

### *Economics Of Manufacture*

This is a subject of such complication and extent that it can merely be mentioned here; for upon it a large treatise might readily be written. It will suffice to say that the prime requisites are the prompt furnishing at all times of materials and tools; the keeping on hand of spare parts of machinery which are liable to breakage or wear; the proper upkeep of all machinery and apparatus; the systematic arrangement for carrying work through the shops, preferably always in one direction; the avoidance of duplication of labor; the prevention of errors, and the speedy correction of those which unavoidably occur; the development of individual efficiency in all employees; the maintenance of a contented spirit among the workmen; and the constant and intelligent supervision of all work.

### *Economics Of Construction*

This subject like the one last discussed is of great complication, and in general principles the two have much in common. For instance, there should be prepared for each piece of construction an elaborate programme, indicating the various steps to be taken and how the work should be carried out. Diagrams in this connection are most useful. Again, there should be prepared a time-schedule for the completion of the various divisions of the work; and this should invariably be lived up to when it is possible.

There should be a pre-arranged schedule for the furnishing of all materials and supplies; adequate means for the transportation thereof should be provided; the workmen should be well housed and fed; and should be made comfortable and contented; disagreements between heads of departments should be prevented; all possible difficulties should be anticipated, and means should be at hand to meet and overcome them; ample funds should be provided for paying promptly all bills for labor and materials; liquor should be kept away from the workmen; and strike organizers and other troublesome people should be run off the job.

All these matters are directly concerned with the economics of construction.

### *Labor*

The scientific handling of labor is an economic problem of the utmost importance, and a treatise could well be written on the subject. The principal desideratum is to keep the workmen well, happy, and contented; and the best ways to do this are to treat them kindly, make them comfortable, feed and house them well, amuse them in their spare time, don't work them too long hours, pay them by piece-work when practicable, listen patiently to their complaints, right their wrongs, see that they are well taken care of when they are ill or injured, and evolve, if possible, some feasible method of sharing profits with them. On the other hand, though, drive them hard and continuously during working hours, insist upon their putting in overtime when the conditions truly require it, discharge instantly all insubordinate or otherwise troublesome men, dispense quietly with the services of all shirkers, and insist that everybody put forth his best and most intelligent effort to effect the maximum of accomplishment in the minimum of time.

### *Waste*

In all lines of activity the avoidance of waste or extravagance and the utilization of by-products are today burning questions; and upon their proper solution by American scientists will depend greatly the success of our country in its commercial struggle with the nations of Europe and Asia. This statement is just as true concerning engineering as it is of any other activity; and it is encouraging to see that a number of our leading technical institutions are inaugurating research departments for the furtherance of this object. Prominent among them in this work, the speaker is pleased to say, is the University of Kansas.

### *Efficiency Experts*

A very new type of specialist in engineering is the efficiency expert—the man who takes hold of moribund factories and other decaying enterprises, studies them thoroughly so as to determine the *raison d'etre* for their decline, evolves the proper remedies for their troubles, puts them again upon their feet, and starts them upon the high road to success. It is mainly in little matters, apparently of small importance, that such concerns fail; and it requires a high development of unusual talent in an engineer to become a truly successful efficiency expert. Such work as his no one can deny being "engineering economics" in the truest sense of the term; and the specialty is surely destined to become more and more popular and important as the years pass by.

# LECTURE II

Having completed the discussion of the principal topics of a general nature pertaining to the economics of designing and construction, it is now in order, as previously explained, to take up the various engineering specialties, concerning the economics of which the speaker has been able to collect sufficient data for his purpose; and these will be treated in alphabetical order. Fortunately (or otherwise) the first of the group is the line of engineering activity in which the speaker has specialized during more than three decades, and in which his numerous writings, extended over a long series of years, deal at great length with the important subject of economy. On that account, the volume of data at hand is unusually large; and this is the explanation of the fact that the treatment of this subject is much fuller in detail than that of any of the others. It is hoped that the speaker will be pardoned for making numerous and somewhat lengthy quotations from his latest treatise, as it was issued only last summer, and as he cannot well improve upon what he has said therein upon the subject of "True Economy in Design".

The great majority of bridge designers believe that the most economic structure is the one for which the first cost is a minimum; and from the contractor's prejudiced point of view this is correct, because his interest generally lies in securing the contract for the work regardless of all other considerations than his own profit; but from the purchaser's point of view that structure is the most economic which will do the work required of it for as long a time as necessary with the least possible expenditure for operation, maintenance, and repairs, all these *desiderata* being obtained with the smallest practicable initial cost of construction.

Treatise after treatise has been written upon the subject of economy in superstructure design, but unfortunately the result is simply a waste of good mental energy; for the writers thereof invariably attack the problem by means of complicated mathematical investigations, not recognizing the fact that the questions they endeavor to solve are altogether too intricate to be undertaken by mathematics. The object of each investigation appears to have been to establish an equation for the economic depth of truss, or that depth which corresponds to the minimum amount of metal required for the said truss; and, to start the investigation, it seems to have been customary to make certain assumptions which are not even approximately correct. For instance, the principal assumption of several treatises in French and English is that the sectional area and the weight of each member of a truss are directly proportional to its greatest stress; or, in other words, that in proportioning all members of trusses a constant intensity of working stress is to be used, while in reality for modern steel bridges the intensities often vary considerably in the same specifications. Again, no distinction is made between tension and compression members, and no account is taken of the greatly varying amounts of their percentages of weights of details.

There is, however, one mathematical investigation concerning economic truss depths which is approximately correct, and which is based on assumptions that are very nearly true; but it holds good only for trusses with parallel chords, for which structures it shows that the greatest ecomony of material will prevail when the weight of the chords is equal to the weight of the web.

It has been found by experience that, for trusses with polygonal top chords, the economic depths, as far as weight of metal is concerned, are generally much greater than certain important conditions will permit to be used. For instance, especially in single-track, pin-connected bridges, after a certain truss depth is exceeded, the overturning effect of the wind-pressure is so great as to reduce the dead-load tension on the windward bottom chord to such an extent that the compression from the wind load carried by the lower lateral system causes reversion of stress, and such reversion eye-bars are not adapted to withstand. A very deep truss requires an expensive traveller, and decreasing the theoretically economic depth increases the weight but slightly; hence it is really economical to reduce the depth of both truss and traveller. Again, the total cost of a structure does not vary directly as the total weight of metal, for the reason that an increase in the sectional area of a piece adds nothing to the cost of its manufacture, and but little to the cost of erection; consequently it is only for raw material and freight that the expense is really augmented. Hence it is generally best to use truss depths considerably less than those which would require the minimum amount of metal. For parallel chords, the theoretically economic truss depths vary from one-fifth of the span for spans of 100 feet to about one-sixth of the span for spans of 200 feet; but for modern single-track-railway through-bridges the least allowable truss depth is about 30 feet, unless suspended floor-beams be used, a detail which very properly has gone out of fashion.

In designing plate-girders, if one will adopt such a depth as will make the total weight of the web with its splice-plates and stiffening angles about equal to the weight of the flanges, he will obtain an economically designed girder, and a deep and stiff one. For long spans, however, this arrangement would make the girders so deep as to become clumsy and expensive to handle; consequently, when a span exceeds about forty feet, the amount of metal in the flanges should be a little greater than that in the web; and the more the span exceeds forty feet the greater should be the relative amount of metal in the flanges.

A rather lengthy mathematical investigation for plate-girders, based upon fairly accurate assumptions, proves that the theoretical maximum of economy exists when the gross areas of flanges and of web at mid-span are equal—a condition readily remembered. Although this is the theoretically correct criterion for economy, if it be applied to any particular case, it will generally be found that the resulting web depth is so excessive as to cause one or more of the following modifications in construction, as compared with the depth which would make the total weight of the flanges equal to the total weight of the web with all its details:

A. An additional splice or two in the web, or else a slightly increased pound price for the large plates.

B. Larger outstanding legs for all stiffening angles.

C. Reduction in the number of cover plates.

D. Narrowing of flange angles and necessitating thereby either an additional bracing frame or an increase in sectional area of the compression flange, in order to compensate for the greater ratio of unsupported length to width.

E. Possible thickening of web because of its greater depth.

F. Possible encroachment on under-clearance in deck spans, or raising of grade to avoid the same.

G. Possible difficulty in fabrication or shipment in case of long or heavy girders because of excessive depth.

Any of these changes would be likely so to upset the economics of the case as to cause a material decrease in the theoretically best depth, hence it is generally advisable to adhere to the rule previously given; but there are occasionally cases where a saving of metal may be effected by making the web depth somewhat smaller, when by so doing a web-splice may be avoided or lighter stiffening angles may be adopted. It should be borne in mind that there is quite a range in web-depths over which the theoretic minimum weight is about constant, unless the thickness of the shallower web must be increased on account of shear; hence one may often vary the dimensions of a plate-girder materially without affecting greatly the matter of economics. In Chapter XXI of "Bridge Engineering" there is given a diagram of economic depths of plate-girders with riveted end connections.

Concerning economic panel lengths, it is safe to make the following statement:—Within the limit set by good judgment and one's inherent sense of fitness, the longer the panel the greater the economy of material in the superstructure. Of course, when one goes such an extent as to use a thirty-foot panel in an ordinary single-track-railway bridge he exceeds the limits referred to, because the lateral diagonals become too long, and their inclination to the chords becomes too flat for rigidity. Again, an extremely long panel might sometimes cause the truss diagonals to have an unsightly appearance because of their small inclination to the horizontal.

There is another mathematical investigation which is of practical value. It relates to the economic lengths of spans, and was first demonstrated in print by the speaker some twenty-six years ago in "Indian Engineering," although the principle was announced three years before then in the first edition of his "General Specifications for Highway Bridges of Iron and Steel". Strange to say, many engineers failed to see that there is any difference between this principle and an old practice of over fifty years' standing. The principle is that "for any crossing the greatest economy will be attained when the cost per lineal foot of the substructure is equal to the cost per lineal foot of the trusses and lateral systems". The old practice was to make for economy the cost of a pier equal to the cost of the span that it supports, or, more properly, equal to one-half of the cost of the two spans that it helps to support. Is not the difference between these two methods perfectly plain? In one the cost of the pier is made equal to the cost of the trusses and laterals, and in the other it is made equal to the cost of the trusses, laterals, and floor system. When one considers that the cost of the floor system is sometimes almost as great as one-half of the total cost of the superstructure, he will recognize how faulty the old method was.

As just indicated, the demonstration referred to proves that in any layout of spans, with the conditions assumed, the greatest economy will be attained when the cost of the substructure per lineal foot of bridge is equal to the cost per lineal foot of the trusses and lateral systems. Of course, no such condition as a bridge of indefinite extent ever exists, nor is the bed-rock often level over the whole crossing; nevertheless the principle can be applied to each pier and the two spans that it helps to support by making the cost of the pier equal to one-half of the total cost of the trusses and laterals of the said two spans.

The principle will apply also to trestles and elevated roads; for in the latter, when there is no longitudinal bracing, if we make the cost of the stringers or longitudinal girders of one span equal to the cost of the bent at one end of same, including its pedestals, we shall obtain the most economic layout. In an ordinary railroad trestle consisting of alternating spans and towers, it will be necessary for greatest economy to have the cost of all the girders in two spans (one span being over the tower) plus the cost of the longitudinal bracing of one tower equal to the cost of the two bents of said tower, including their pedestals.

The economics of reinforced concrete bridges have not received much attention from technical writers; and they are rather difficult to determine, as the quantities involved are influenced quite largely by the individual taste of the designer. The problem is also complicated by the facts that the unit costs of the various portions of a structure may be more or less different, and that the unit costs of different types of construction may be decidedly unlike. In general, it may be said that the unit costs are lower for those structures which have the simplest formwork; and a reduction will also be effected by decreasing the area of form-surface per cubic yard of concrete. For instance, in the case of a wall or slab the form-cost per cubic yard will vary practically inversely as the thickness of the said wall or slab. Evidently, therefore, it is desirable to concentrate the concrete into a few large members, rather than to employ a great number of small ones.

It should be noted that reinforcing bars less than ¾ in. in diameter command higher pound prices than do the larger bars. The extras for these small bars may be found in *Engineering News* the first of each month.

Taking up, first, girder bridges carried on columns, the following points must be considered:

First. The panel length, when cross-girders are employed.
Second. The number and spacing of the longitudinal girders.
Third. The number of columns per bent.
Fourth. The span length.
Fifth. The use of reinforced concrete piles to carry the footings.

The panel length adopted is usually not of great importance from the standpoint of economy. Lengths of from eight to ten feet are generally employed; but a considerable variation from these values will cause little change in the combined cost of the slabs and cross-girders. A reduction in concrete quantities can frequently be effected by using long panels, and by carrying the slabs on short stringers supported by the floor-beams; but the extra form-work required will generally overbalance this saving in volume.

The number and spacing of the longitudinal girders will depend upon the width and the height of the structure, the span-length, and the load to be carried. For a high structure in which the economic span-length is fairly long, it will nearly always be found best to employ two lines of girders, the spacing thereof being equal to about five-eighths of the total width of the structure; but for bridges much over sixty (60) feet wide, the use of three or even four lines may be preferable. The slab in such structures is carried on cross-girders and cantilever-beams. For a low bridge in which the economic span-length is short, it will generally be the cheapest to omit the cross-girders, except at the bents, and to employ several lines of longitudinal girders. The wider the structure, the more likely will this arrangement prove to be economical; and very heavy loads also favor its adoption. For a structure in which the span-length is from one-half to two-thirds of the width, it will usually make little difference which of the two types is adopted, unless the height is rather large; and even in extreme cases the variation between the two is not likely to exceed ten per cent. Ordinarily, it will be found more desirable to use two lines of girders, with cross-girders and cantilevers about eight or ten feet centres.

The proper number of columns per bent depends on the number of longitudinal girders. When there are only two lines, two columns will, of course, be employed. When there are several lines of girders, there should generally be one column per girder in low structures, and two columns per bent in higher ones. In this latter case a heavy cross-girder will be required at each bent to carry the longitudinal girders.

The economic span-length is affected by the height and the load, being larger for greater heights and smaller for heavier loads. An approximate value thereof is given by the formula

$$l = h\left(0.8 + \frac{2000}{w + 1000}\right)$$

in which $l$ = economic span length, centre to centre of supports,

$w$ = load per lineal foot of girder (excluding its own weight),

and $h$ = fixed height of structure.

The quantity $h$ represents in any given case the height which is fixed, such as the height from grade to top of footing, height from grade to bottom of footing, height from underside of girder to top of footing, or height from underside of girder to bottom of footing, as the case may be. There is always a considerable range of lengths for which the quantities remain nearly constant. The formula gives values a trifle greater than those for which the quantities are a minimum, since the use of heavier sections will reduce slightly the unit costs of the concrete.

Reinforced-concrete piles should be used under footings when a suitable foundation is to be found only at a considerable depth, or when a very large footing area would be required in order to reduce the pressure to a proper amount. A comparison must be made for each case as it arises, allowing properly for the cost of the column shaft, the footing, the piles, and the excavation. This latter item must not be overlooked.

In arches the problem is much more complicated than in girder spans. The factors that affect the economic lengths are the cost of the arch ribs and that of the piers and abutments, the dividing lines between them being the verticals through the springing points. For any fixed span-length the greater the rise, up to a limit of nearly one-half of the opening, the smaller will be the costs of both the arch and the piers or abutments which sustain it; but in most cases the distance from grade to ground is too small to permit the adoption of such a large rise; hence the problem generally resolves itself into a determination of the question, "How long can the span be made economically for a certain limit of rise?" This will be influenced by several important considerations, among which may be mentioned the following:

A. The live load used.

B. The amount of earth fill, if any, over the arches.

C. The depth of the foundations for the piers and abutments below the springing points.

D. The cost per cubic yard for putting the bases of piers and abutments down to a satisfactory foundation.

E. The necessity for a heavy or substantial appearance of the piers and abutments.

F. The height to which the large pier shafts must be carried.

G. The condition of the arch barrel—whether solid or ribbed.

H. The necessity, or otherwise, of adopting certain span-lengths to meet existing conditions.

Here are too many variables for a theoretically correct economic investigation, hence the surest and most satisfactory way to proceed is to make by judgment the best possible layout consistent with the conditions, then two others, one involving a span-length a certain number of feet greater and the other a span-length the same number of feet less, and figure the costs of arches and piers (or abutments) for all three cases. Instead, though, of increasing and decreasing the span by a certain number of feet, it may be necessary to reduce and augment the number of spans by unity. After the costs of the arches and piers or abutments are found and properly combined, the cost of these two portions of the construction per lineal foot of span for each of the three layouts can be computed and compared. The one which gives a minimum will indicate approximately the best span-length to adopt.

In some cases it will prove to be economic to make the middle span of the bridge a certain length and reduce gradually the lengths of the spans at each side. If the configuration of the crossing will permit of a symmetrical layout on this basis, the effect will prove to be pleasing to the eye and generally economic of first cost, especially if a constant ratio of rise to span be maintained; because, as far as cost of substructure is concerned, the overturning moments from live load on a single span only and from inequality of dead load thrusts are kept low, owing to the fact that the lighter thrusts in the smaller span act with a greater lever arm than do the heavier thrusts of the longer span, on account of higher location of the points of springing. In adopting this expedient, though, care has to be exercised to prevent the principles of æsthetics from being violated.

There are many minor economic questions that arise in the designing and construction of bridges, among which may be mentioned the economic greatest lengths of different types of spans; the character of approaches to bridges; column spacing in bents supporting cross-girders with cantilever brackets; the economic functions of swing spans, cantilever bridges, arches, and steel trestles; the height of concrete retaining walls at which it is economic to begin to use reinforcing; the relative economics in employing medium steel, soft steel, standard steel, and alloy steel for bridge superstructures; the effect of erection on the economic layout of spans; the comparative economics of rim-bearing and centre-bearing swing-spans; economy in choice of metal sections; and economy in shopwork. These various economic questions will now be taken up in the order enumerated.

Comparing rolled I-beam and plate-girder deck spans for modern heavy live loads, the weights of metal are about equal for spans of fifteen feet; but the former are cheaper per pound than the latter by about four-tenths (0.4) of a cent, consequently the costs per lineal foot erected are equal for a span of about twenty feet.

Comparing deck plate-girders and through, riveted truss-spans, for which there is usually a difference of about one-half cent per pound erected in favor of the former, the weights of metal per lineal foot are the same for spans of one hundred and fifteen (115) feet, which is about the extreme limit of length for plate-girder spans shipped in one piece; hence it may be concluded that for all practicable lengths, deck plate-girder spans are more economic than through, riveted truss-spans. Besides, the use of such deck spans effects a great economy in the substructure by reducing the length of each pier from six to ten feet, the longer the span, of course, the less the reduction. It generally reduces also the heights of the piers.

Comparing half-through, plate-girder spans and through, riveted truss-spans, for which there is a difference of about two-tenths (0.2) of a cent per pound erected in favor of the former, the weights of metal per lineal foot are the same for spans of seventy (70) feet, but the costs per foot are about equal for spans of seventy-five (75) feet. However, as plate-girder spans are in many respects more satisfactory than short, through, riveted spans, the dividing point is generally placed at about one hundred (100) feet.

Comparing Pratt and Petit truss-spans, for which there is no difference worth mentioning in the pound prices of the metal, the weights per foot (and therefore the costs) are alike for single-track spans of three hundred (300) feet, and for double-track spans of three hundred and fifty (350) feet; but both constructive and æsthetic reasons necessitate limiting the lengths of Pratt trusses to about three hundred and twenty-five (325) feet.

The economics of approaches to bridges will involve the question of whether it is best and cheapest to build earth embankments, timber trestles, or steel viaducts, and at what heights it would pay to change from one kind to the other. It can be readily solved by employing the numerous diagrams of Chapters LIII to LVI, inclusive, of "Bridge Engineering".

The economics of column spacing for bents when cantilever brackets are employed is an interesting little problem, but the final determination must be in accordance with good judgment as well as economy; for if the spacing be too small, rigidity is likely to be sacrificed. Upon certain assumptions of approximate correctness, the mathematical solution of this problem is a possibility; but the equations involved would be so complicated that it is much better for any particular case to assume two or three spacings, compute the total weight of metal in the bent for each, and find the one which will give approximately the least weight of metal. If the columns are placed at the quarter points of the beam, the dead load bending moment at the middle will be approximately zero; and if the effect of stress reversion is ignored, the direct and reverse bending moments for the central portion of the beam will be equal, and this arrangement would be about the most economical possible. But if the reversion is considered, the sectional area of the middle portion of the beam must be greater than that of the outside portions, hence for economy its length should be somewhat less than one-half of the total, and the columns would then be spaced somewhat closer than when they are located at the quarter points. The fact that the brackets are usually lighter near the outer ends than at the inner ones would, for economy, tend to draw the columns together; but on the other hand this would increase the weight of the splices and connecting details. The proper column spacing to adopt will depend upon the length of the columns; for it is easily conceivable that the structure could be so high and so narrow that the quarter-point spacing would be too close for proper resistance to wind pressure. Again, in such a case the wind load might be so great as to necessitate an increase in column section above that required to care for the live and dead load stresses only; and thus the effect of wind pressure would enter the economic study. It will be found in most cases that it is inadvisable to space the columns much less than one-half of the total length of the beam.

The economic functions of swing spans are somewhat difficult to formulate. The minimum perpendicular distance between central planes of trusses for first-class construction should be the same as for simple-truss spans,—viz., one-twentieth of the span length. It is evident, of course, that the narrower the bridge the less it will weigh and cost. The truss depths at ends of through swing bridges are generally determined by the clearance requirements; but in long spans it is sometimes advisable, for the sake of vertical stiffness and to avoid the raising of span-end from a load on the other arm, to make the said depths still greater. As a rule, this increase is not of an uneconomic nature. For long spans, or those exceeding, say, four hundred (400) feet, the truss depth at outer hips should be about one-fourteenth ($\frac{1}{14}$) or one-fifteenth ($\frac{1}{15}$) of the total span length. The truss depth at the inner hips should generally be from one-ninth ($\frac{1}{9}$) to one-tenth ($\frac{1}{10}$) of the total span length; and when towers are used, their height should generally be from one-sixth ($\frac{1}{6}$) to one-seventh ($\frac{1}{7}$) of the span. Of course, the æsthetic features of the design should govern greatly the determination of all these depths; and, fortunately, any moderate change in them does not affect materially their economics.

In swing spans it is evident that, as far as is consistent with safety, the diameter of the drum for economy should be made as small as possible, not only because this effects a saving of metal, but also because it reduces the diameter, and therefore the cost, of the pivot pier. For spans of moderate length and width there is generally a small economy in centre-bearing swing-spans over rim-bearing ones, especially as the former sometimes permit of smaller pivot piers, but the difference is often inconsiderable. There is a limit to the size of centre-bearing swing-spans due to the objectionable feature of concentrating great loads upon small areas and to the necessity in the case of very wide spans for excessively heavy cross-girders. The question of economics between the two styles of swings is one that has to be determined for each special case as it arises by preparing actual estimates and not by *a priori* reasoning.

In respect to the economics of cantilever bridges the following may be stated:

FIRST. The economic length of the suspended span is about three-eighths ($\frac{3}{8}$) of the length of the main opening, but a considerable increase or decrease of this proportion does not greatly change the total weight of the metal.

SECOND. The most economic length of anchor arms, where the total length between centres of anchorages is given, and when the main piers can be placed wherever desired, is one-fifth ($\frac{1}{5}$) of the said total length. By keeping the anchor arms short, the top chords may be built of eye-bars, provided that, with the usual allowance for impact, there is no reversion of chord stress; and this effects quite an economy of metal. But it is conceivable that cases might arise where, from danger of washout of falsework, eye-bar top chords would be objectionable; hence this method of economizing must be used with caution.

THIRD. In respect to the economic length of anchor-span in a succession of cantilever spans, it may be stated that within reasonable limits the shorter such anchor-spans are the greater will be the economy involved; but, generally, navigation interests will prevent their being built as short as might be desired. If permissible, they may be made so short that, as in the case of anchor-arms, eye-bars may be used for the top chords, thus effecting a decided economy of metal, although shortening the anchor-span increases proportionately the stresses on the web members and the weights thereof.

The question of what is the economic limit of length of simple-truss spans as compared with cantilevers is still a mooted one. Professors Merriman and Jacoby place it in the neighborhood of six hundred (600) feet, but the speaker has had occasion to compare simple-truss spans of seven hundred (700) and eight hundred (800) feet with the corresponding cantilever structures, and has found the former more economic. The continuity of cantilever spans in resisting wind loads lowers the requirement for minimum width from one-twentieth ($\frac{1}{20}$) to about one twenty-fifth ($\frac{1}{25}$) of the greatest span-length, and hence, because of substructure considerations, gives an advantage to the cantilever type that in certain extreme cases will more than offset its disadvantages of greater weight of truss metal.

There are certain legitimate economies that may be employed in the designing of cantilever bridges, among which may be mentioned the following:

A. The wind pressure assumed in computing the erection stresses may be taken lower than that given in the specifications for the finished structure, provided that the full wind pressure would not overstress any of the metal seriously or involve any risk of disaster during erection. A stress of three-quarters of the elastic limit of the metal applied a few times during erection would do no harm, and the chance of there being in that limited time any wind pressure at all approaching in magnitude that specified is very small. This lowering of the intensity of wind pressure may be the means of avoiding, in a perfectly legitimate manner, the increasing of the sections of a number of truss members because of erection stresses; but such economizing should be done with caution after a thorough consideration of its greatest possible effects.

B. A certain amount of metal can sometimes be saved by splaying the trusses between the main piers and the ends of the cantilever and anchor arms; but unless the amount thereof be fairly large, the extra pound price of the metalwork in the cantilever- and anchor-arms due to the said splaying may more than offset the value of the reduction.

C. A small economy may sometimes be accomplished by omitting during erection from the cantilever portion of the structure all parts that are not essential to its strength before the coupling of the cantilever ends is effected, thus reducing the erection stresses a little.

D. Solitary piers or large pedestals under the main vertical posts are sometimes just as satisfactory in every way as long, continuous piers, especially if a connecting wall of reinforced concrete between them be employed. Generally they will be found to involve a large saving in the cost of the substructure.

E. In very wide cantilever bridges it might sometimes be advisable to adopt intermediate trusses so as to economize materially in the weight of the floor-beams and a trifle in that of the trusses, also because of the consequent reduction in dead load, but mainly so as to keep within reasonable limits the sizes and weights of the pieces to be handled and thus economize on the size of the traveler and the cost of the erecting machinery. On the other hand, though, increasing the number of trusses is likely to increase a little the percentage of weight of truss details; but where the sections of members are large this increase would be small. In case the wind stresses are an important factor in the proportioning of the truss members, the employment of an interior truss or interior trusses might, by the reduction in areas of chord sections, cause such relatively large wind stresses on the chords of the exterior trusses that the additional metal required to take care of them would offset all the saving obtained in the ways just mentioned.

F. In long-span cantilever bridges the stresses on the truss members that rest upon the piers should be divided among as many such members as possible by using an inclined strut on each side as well as a vertical post instead of carrying all the loads to the top of the latter by tension members, as was done in the design of the ill-fated Quebec bridge. Again, if a lowering of the inner ends of the cantilever arms be permissible, the inclining of the end sections of the bottom chords to the horizontal will take up a portion of the load that is carried to the pier and thus will reduce the stresses on the vertical and inclined posts assembling there. This last feature reduces also the total cost of the masonry by diminishing the height of the main piers, and saves placing the tops of the trusses at an abnormal height above the water.

G. If there be any choice between the riveted and the pin-connected types of construction for any cantilever bridge, it is generally better to adopt the latter, because, as cantilever bridges are usually employed for long spans only, pin-connected work is the more suitable. Again, it is a little lighter than riveted work, and therefore the dead load on the structure would be somewhat less. On the other hand, the riveted construction is so much more rigid than the pin-connected that it is preferable to adopt it whenever the conditions permit; besides, in the riveted work it is not necessary to stiffen any truss members for erection, although it might be obligatory to increase a few of their sectional areas.

H. Very large compression members should be made of box section so as to do away with latticing. This not only effects an improvement in the design, but also saves some metal, although the details required at the panel points to distribute the stresses from the cut cover plates tend to offset the saving in weight of lattice bars and stay plates.

Questions of erection often not only affect the economic layouts of crossings but also determine the character of the spans to be adopted. For instance, if the danger from washout of falsework be great, either a cantilever or a semi-cantilever structure may be better than one of simple spans, or a pin-connected structure may be preferable to a riveted one, even if the computations of cost made upon the basis of good luck in erection indicate that the contrary is the case. Again, the chance of not getting the substructure finished before high water or bad weather causes a cessation or partial cessation of work might so affect the layout of spans for a bridge as to increase materially the cost thereof; therefore, the expense involved by taking precautions to avoid possible delay would be in the nature of true economy.

In the proportioning of main members of bridges, and even occasionally in the detailing, small economies may be effected by choosing the regular and least expensive sections. Plates and angles are at times cheaper than channels or I-beams, and at other times more expensive. Z-bars are sometimes higher and are always difficult to obtain. Deck beams are invariably high priced, and tees are generally so. Many designers are not aware that I-beams over fifteen (15) inches deep cost one-tenth ($\frac{1}{10}$) of a cent per pound more than those fifteen (15) inches and under in depth, and that angles having one or both legs longer than 6 inches are subject to the same increase. There is a long list of special prices, too, on very small angles. Not infrequently it will be cheaper to use the larger of two small angles, even though more weight be involved; and special angles such as those of 7 by 3½ in. section are always more expensive than the standards, besides being more difficult to obtain. Current prices of the various sections are to be found in *Engineering News* the first of each month. Since the organization of the United States Steel Corporation, the variations in pound prices of the numerous shapes of bridge metal in this country are less than they used to be; but they are still sufficient to make a material difference in the cost of structure: whereas, for Canadian and other foreign work, very large differences may be created by the selection of the material, owing to the variation in the customs duties. It behooves the expert bridge designer to keep posted concerning variations in metal prices and import duties for the different sections. The Bethlehem Steel Company manufactures, by means of a combination of vertical and horizontal rolls acting simultaneously, some special sections for I-beams that are exceedingly light for their strength; and, although the company asks a small extra price for such sections, it generally proves economical to employ them.

The duplication of a whole structure, or any parts thereof, effects a large proportionate saving in the shop. Of course, if two spans or other units can be made alike, entire groups of drawings are saved; and it is a large part of the function of the detail shop draftsman to duplicate individual parts and to group partially-unlike members. By duplication, in addition to a saving in drawings, there is a saving of templets, a saving of shop supervision, a saving of the writing of shop bills, a saving of making extra material lists, a large saving in errors, and a considerable saving in the field due to the avoidance of loss of time in the selection of the proper parts; for if there is much duplication, there is much more possibility of the right parts being at hand. Duplication extends into very small details; in beam work the end connections are made alike, and instead of being shown on the drawings, their numbers only are given. Likewise the templets for such end connections are made permanent; and they, too, are referred to only by number and are used over and over again. On large structures, batten plates, lattice bars, and other similar and oft-repeated elements can be duplicated with great advantage. For instance, identical lattice-bars save the resetting of the gauge on the lattice-bar punch, and also the labor of selecting in assembling the material, besides considerable expense in handling. It may at times require more material to duplicate the parts of a structure, and yet it may result in a net saving in the cost of construction; for, although the metal be ordered by the pound, if the evidence of duplication of shopwork is made clear in the drawings submitted to bidders, a lower pound price will be named.

Blacksmith work of any kind is always the most expensive work in a bridge shop, and it should be avoided to the utmost, not only because it is not commonly well done but also because it costs heavily in the drawing room, in the templet room, in the forge shop, and in punching, fitting, and assembling. If forging is essential, it should be done in duplicate as much as possible, so that dies may be made.

There is a small economy or the reverse involved in the crimping of stiffening angles for plate-girders; and the officers of the different bridge shops have widely varying ideas as to whether it is better or not to crimp them. The economy will depend upon their strength and the amount of offset, for the question involved is whether the cost of crimping the ends does or does not exceed that of furnishing and putting in the filling plates. The cost of the freight on the filling plates is often the determining factor in settling whether it is finally more economic or otherwise to crimp stiffening angles, and this feature of the question should be borne in mind by the designer. This matter of cost of freight and other transportation of metal to bridge site applies to the design of a bridge as a whole as well as to the question of crimping.

There is often a material difference between the lightest possible bridge and the most economic one, not only on account of the reduction of cost of fabrication but also because of that of erection; and the designer, in order to obtain the best possible results for all cases, must be well posted on all the important details of both shopwork and field work. He should know almost instinctively what is easy and what is difficult to manufacture and to erect; and especially should he recognize when rivets can and when they cannot be driven by the various kinds of apparatus used in shop and field.

In the design of new bridges to replace old ones, the erection should be given full and thorough consideration, since a large amount of the labor of replacing the old structure under traffic may be saved if the new one have panels of such length as not to interfere with the metalwork of the old bridge. There are many other ways in which advantage may be gained by thoroughly considering the erection at the time the new structure is designed, such, for instance, as the supporting of the old stringers on advantageously located falsework until the new girders can be placed, and the shipping of the plate-girder spans riveted up complete instead of requiring that they be assembled in the field.

In all work of designing, the cost of the materials at the site should be studied very carefully, since local prices will often enable the designer to effect a great saving. Where the work is scattered over a wide field, the matter of cost of materials becomes exceedingly important and often changes the type of the structure. For instance, in designing a highway bridge for the Western Coast, it should be remembered that steel stringers become very costly as compared with the lower-priced wooden stringers of that country. The opposite conditions obtain in the eastern part of the United States. The prices of gravel for concrete work, or of very cheap stone, may affect the type of piers employed. The engineer should know markets even better than the contractor, but commonly he does not, and he will often demand an expensive material where a cheaper one would serve his purpose quite as well. Rough averages of prices per unit in place are very apt to produce flaws in the economy of a design.

There is an economic feature of bridge building that is worthy of special mention, in that it effects a large saving in first cost, maintenance, and repairs, often for a number of years. It is the designing of cantilever brackets to carry in the future wagonways, footwalks, and even street railways, and omitting putting them in until required, but providing all the rivet-holes for the future connections. In such cases, of course, the trusses must be made strong enough to carry the additional live and dead loads, and the counterbracing must be figured for both the future and the immediate dead loads.

A question sometimes arises as to whether it is more economic to support a pavement on buckled plate or on reinforced concrete. The latter is cheaper for trestles and short spans, but not for long ones. However, the deterioration of the buckled plates, due to moisture and smoke fumes, should receive adequate consideration. Moreover, the latest experience shows that very heavy concentrated live loads are liable to spring the buckled plates and break up the paving.

Some of the most modern problems in bridge economics are those due to the advent of reinforced concrete construction. For instance, in highway bridge building there arises the general question as to whether it is advisable to adopt reinforced concrete or steel; and for spans under one hundred feet in length, when due consideration is paid to the factors of maintenance, depreciation, and repairs, the former will usually be found the more economic. In the future this limit of span-length for economy will certainly continue to increase; and probably even today it has been passed in some localities.

Another problem is whether in reinforced concrete construction it is preferable to adopt the arch or the girder type. Unless the spans are quite long, the latter will generally be the cheaper, but the former is the more æsthetic, although by curving the bottoms of the concrete girders, as was done on the Twelfth Street Trafficway Viaduct in Kansas City, a very pleasing effect can be secured.

Another economic problem is whether to adopt a wooden or a reinforced concrete floor in a steel highway bridge; and, when danger from fire, cost of maintenance, etc., are considered, the decision should invariably be in favor of the permanent construction.

Since the late occurrence of partial destruction by fire of several large highway bridges carrying creosoted block pavement resting on creosoted planks, the question has arisen as to how much more it would have cost to rest the pavement on reinforced concrete. The layman has an idea that the amount is very small, being merely the difference between the value of the reinforced concrete slab and that of the creosoted planks; but such is far from being the case, for the large difference between the weights of the two bases adds materially to the dead load that has to be carried by both the floor system and the main girders or trusses.

In the case of a steel viaduct, the question sometimes comes up as to the economics of making the bents of reinforced concrete instead of steel; and for heights not greater than forty or fifty feet the concrete is likely to win; but with braced towers the steel will generally prove the cheaper. In solitary bents of reinforced concrete attention must be paid to the bending effect of longitudinal thrust, and this is likely to prove an important factor in the determination of the economics of the layout.

There is an economic question to which, as yet, but little attention has been paid,—viz., the comparative costs of cantilever and suspension bridges. Until 1911 nothing of any value had been published concerning the length of span at which a suspension bridge becomes cheaper than a cantilever, each bridge specialist having had a vague idea of his own concerning the question. The speaker for years has believed the dividing length to be in the neighborhood of 2,000 feet, but has recognized that it will vary considerably for different crossings on account of the governing conditions. If the question were one of superstructure alone, it would readily be capable of solution, but the substructure plays an exceedingly important part therein. Dr. Steinman places the dividing span-length (based solely on economic reasons) between cantilever and suspension bridges at about seventeen hundred (1,700) feet; but certain assumptions differing from his concerning schedule prices and other ruling conditions would have increased somewhat this limit.

The economic depth for stiffening trusses of suspension bridges has been determined theoretically by Dr. Steinman. He finds that it is about one-fortieth ($\frac{1}{40}$) of the span, and states that this is somewhat higher than the average of past practice, probably because most designs have been a compromise between the demands of economy and those of æsthetics. In his opinion, the Williamsburg Bridge, which is the only long-span structure conforming to this economic ratio, is marred in appearance by the excessive depth of the stiffening trusses. This limit does not strike one as being very high, though, considering the fact that the trusses are generally through ones and that they must provide a clear headway ranging between twenty and twenty-five feet. If twelve hundred feet be taken as the minimum span-length for which it would be legitimate to consider the adoption of a suspension bridge for railway traffic, the economic truss depth would be thirty feet, which is a little shallower than it is practicable to adopt for a double-track bridge with floor-beams and portal bracing that have ample depths for rigidity. A serious objection to employing shallow deck stiffening trusses is their unsightly appearance. All things considered, it is generally advisable to make the truss depth as shallow as the governing conditions will allow, provided that the economic depth be not varied from too radically.

The inferior limiting ratio of distance between central planes of stiffening trusses to span-length has not yet received due attention by engineering writers. The speaker is of the opinion that it ought to be about as one is to thirty, that for simple spans being as one is to twenty. There are two good reasons for placing a minimum limit to this ratio,—viz., to avoid vibration and to make the various compression chords, which, in a way, form one long strut of the same length as the span, have a reasonable ratio of length to radius of gyration. For the thirty-to-one limit the ratio of length to radius of gyration would be about sixty, which is well within the bounds of good practice in strut proportioning.

The economic cable-rise for many years has been recognized as varying from one-tenth to one-eighth of the span length. For bridges in which the side spans are without suspenders, Dr. Steinman finds that it is about one-ninth of the main span, and for those in which the side spans are suspended from the backstays it is about one-eighth thereof.

The number of arch bridges built up to the present time is comparatively so small, and the economic studies thus far made on arches have been of such an approximate character, that but little reliable information concerning the comparative economics of the various types is available. There is a general impression that the smaller the number of hinges the greater the economy, but there are conflicting opinions concerning that view. Again, it is probable, but not yet proved, that for exactly similar conditions of layout and loading a cantilever-arch bridge is a little less expensive than an ordinary arch with two flanking simple spans. Finally, the three standard kinds of ribs for fairly long spans in the order of their economy are generally supposed to be the spandrel-braced, the braced-rib, and the solid-rib types; but differences in the existing conditions at crossings may vary this order in certain cases.

Another economic question in bridge engineering that has arisen of late years is the economics of movable spans, or the choice for any crossing between the swing, bascule, and vertical-lift types. The settlement of this question is by no means an easy matter, for it will depend greatly upon the special conditions affecting the particular crossing under consideration. When the swing-span type is pitted against either of the others, the first point to determine is what proportionate length of single opening is equivalent to the two openings afforded by the rotating draw. This is a matter of personal opinion, and even in one man's mind it might vary materially for different cases. Under ordinary conditions, the speaker believes that a single clear opening twenty-five (25) per cent greater than either of the clear openings afforded by the swing type will give equally good or better facilities for navigation, and that under the worst possible conditions the excess percentage need not be more than forty (40). Unfortunately, though, neither the speaker nor the designer of the bridge under consideration has anything to say about deciding this point, because the court of last appeal is always the War Department. If that department deems that the clear opening or openings suggested by the designer be insufficient, it has no hesitation whatsoever in saying so and in compelling the petitioner for approval to increase the said clear opening or openings as much as its engineers consider advisable. Up to the present time the War Department has almost always accepted plans of the speaker's in which the excess percentage referred to has been twenty-five or even less; but its having done so in the past is no reason for assuming that its engineers will always be willing to recognize that percentage as their maximum requirement. Accepting this settlement of the question as fixed, it is practicable to compare swing spans with bascules and vertical lifts.

In most cases when swing spans and bascules are compared, the result is either a stand-off or more or less in favor of the bascule. The conditions would be unusual where the swing proves to be much more economic—for instance, where the deck is very close to the water, thus necessitating a well or wells for receiving the counterweighted end or ends of the bascule.

In almost no practicable case is the swing materially more economic than the vertical lift, unless, perchance, the opening be very narrow, the vertical clearance very great, and the depth of the bed rock small—a most unusual combination. In almost every case of comparison which has occurred in the speaker's practice the vertical lift has proved less expensive than the rotating draw.

Considering now bascules and vertical lifts, in most cases the economic comparison favors the latter type. It always does so if the vertical clearance is not in excess of fifty or sixty feet. If the clearance be the usual one for ocean-going vessels,—viz., 135 feet, the cost of the bascule and that of the vertical lift will be equal for clear openings of about one hundred feet or, in extreme cases, one hundred and twenty-five feet. The longer the movable span, the closer the deck to the water, the deeper the bed-rock, or the smaller the required vertical clearance, the greater will be the comparative economy of the vertical lift.

As before indicated, the treatment of the economics of bridge designing has been made much more elaborate and exhaustive than that of any other specialty. For this there are four reasons,—viz.:

FIRST. It is in the lead alphabetically on the list of specialties discussed.

SECOND. The science of bridge design has been more deeply and systematically studied than that of any other branch of engineering.

THIRD. It is deemed advisable to give an example of the thorough treatment of economics in at least one engineering specialty.

FOURTH. Bridge engineering is the one specialty for which the speaker feels capable of writing a truly exhaustive treatment of the question of economics.

For these reasons he trusts that his hearers will pardon him for taking so much time for the detailed discussion of "bridge economics".

# LECTURE III

## City Planning*

The salient feature of economics in design and construction, so far as engineering is applied to city planning, may be said to lie (as in other engineering work) in a *more or less accurate adaptation to purpose*. In city planning, the engineer endeavors to determine, for example, the width which any street ought to have, so that it shall not wastefully be made wider than necessary, nor, on the other hand, shall it prove too narrow to perform properly the traffic function which pertains to it. He determines whether it shall be a traffic artery, a secondary street, or a purely domestic street. In so doing he is able to determine not merely its proper width, but also the strength and the character of the pavement it should have, and the relative allotment of space to roadway, sidewalks, etc.

The districting of the city for different uses, the control of building heights, and many other phases of city planning that have as their ultimate object the possibility of greater adaptation to purpose, are economic considerations, which often are of paramount importance.

## Dams†

The following are some of the salient economic questions in the designing and building of dams:

Should dams be of earth or masonry?

If of earth, should there be a concrete, a puddle, or a soil core, or none? What slopes should be used on upstream and downstream faces? What pavement or other protection on the slopes? How should the earth be compacted?

If of masonry, should the dam be curved in plan or straight? This will depend upon the nature of the site, the length of structure, and other numerous conditions. Should it be of concrete, or cyclopean, or rubble? Should it be massive,—*i.e.*, solid construction, or of the reinforced, hollow type? If of concrete or cyclopean masonry of the solid type, should it be built in forms or faced with pre-cast concrete blocks, or faced with stone? What margin of safety should be provided? This will depend upon the importance of the water impounded by the dam, the risk to life and property below, and the available funds, as well as other considerations.

All these are economic features of importance that affect the designing and construction of dams.

## Electric Railways

In the "*Proceedings* of the Engineers' Club of Philadelphia" for July, 1914, there is a paper by E. P. Roberts, Esq., C. E., entitled "Reporting on Public Service Properties", in which is treated in great detail the subject of the economics of electric railways. As no better presentation

*Data furnished by Chas. Mulford Robinson, Esq., C. E., professor of civic design in the University of Illinois.

†Data furnished by Alfred D. Flinn, Esq., C. E., deputy chief engineer of the Board of Water Supply of New York City.

thereof could well be made, that portion of the paper relating to the said subject, is reproduced nearly verbatim as follows:

### *General Survey*

First, obtain a bird's eye view of the territory. To secure this, make a preliminary study of all available maps, including topographical, and note the general location of the proposed road, the location of the territory which apparently might be served, and such factors as might seem until definite information is obtained, to restrict or to enlarge the territory served, to a greater degree than would be the case if it were based upon a strip two or three miles on each side of the road. An arbitrary assumption of uniform width of territory served is misleading. Location of rivers paralleling the route, high ridges or hills near the right-of-way, other railroads, either paralleling or at an angle to the proposed road, and other physical and transportation features—all affect the ease of access to the road, the traffic which should be secured, and the service which should be offered.

### *Industrial Developments*

Having in mind a possible general location, then some preliminary knowledge of the characteristics of the territory is helpful before going over the route.

What is the general character of the industries? Why did they develop? Upward or downward tendencies? What probable future? Can the proposed road help the development?

Mining—fluctuating in value to an electric road.

Manufacturing—less fluctuating in value to an electric road, but unless diversified, quite variable.

Agricultural—usually less tendency to fluctuation, but depends somewhat upon nationality of farmers; generally a farming community spends less money for unnecessary riding than does a mining or a manufacturing community.

Study census reports showing growth (or decrease) of population. School, voting, and other records stating population, etc., can be studied later.

Note the characteristics and the tendencies of growth of the principal terminus.

Of secondary terminus.

Of intermediate territory.

Note direction of existing railroad traffic. Why have the roads such directional location? Existing business and social relations have built up a certain direction of travel; and if the proposed road does not serve such existing traffic tendency, what reasons are there for presuming that the direction of movement can be changed? Make note of this to ascertain more accurately later. It requires exceptional conditions to deflect existing directions of travel.

The location of an existing road may have resulted from either through or local traffic conditions. If the former, and local conditions make a cross-country road desirable, then the traffic condition for the proposed road may be excellent, but, in this, as in every other matter, all statements must be carefully weighed, and the facts must be ascertained by investigation.

*Inspection Of Route And Territory*

Being now prepared to appreciate what is seen, a rapid trip over the route is advisable, but not giving too much attention to detail, and not reaching definite decisions. It will be time enough later to consider the equivalent of 5-ft. contour lines: 50-ft. ones are sufficient at this stage. During such a trip, intelligent and applicable questions can be asked, and the answers recorded, but not necessarily digested (and certainly not evaluated) until later. Frequently, printed forms can be left with bankers, secretaries of chambers of commerce, etc., to be filled in and mailed, or, preferably, collected and discussed on a return trip.

A return trip can next be made and somewhat more leisurely, and giving more attention to details, topography, character of soil, width of rivers, heights of banks and of high water, character and growth of industries, crops (gross and per acre); also probable effect of the proposed road on the character of crops, present routing and market, population, growth, and characteristics. Industrial and sociological information of all kinds, bank reports, building loan reports, etc., all are important. In each case comparative statistics extending over a period of years should be obtained —tendencies and direction of growth, and especially of decay, should be noted and the reason ascertained.

Present traffic and reason for traffic should be noted. How much of the existing traffic will the proposed road obtain? Probably little, if any, of such traffic as originates or terminates beyond its terminals—probably a large part of that which is local between such terminals.

From information as to amount and direction of traffic and knowledge of general conditions affecting cost of construction, and having considered strategic position, then a tentative location can be considered. If the country is rather rough, a survey of one or more routes may be advisable; if it is comparatively level, the survey may be postponed. When to make survey depends on the time available, the season of the year, and other factors, including the advisability of appearing to be busy, and of surveying more than one route in order to obtain interest and competition. This is about the only time when anything will be "given" to the road.

*Tentative Plan*

The tentative plan will be based on such ruling and maximum grades as the engineer's experience indicates to him will probably prove, after further examination, to be about right, considering the magnitude and direction of traffic, topography, etc. Carried along with consideration of locations, grades, etc., will be preliminary studies of the equipment which will be necessary to handle the traffic, of the character of service best fitted to the conditions, and of the general type of equipment best suited to the service to be given.

Tentative train sheets should be prepared, and the comparative advantages and disadvantages tabulated. Effect on platform charges (exceedingly important), effect on total and maximum peak power (as to each substation and as to power house), location of passing points, relation of the same to grade, meeting at central points in town, and whether advisable or not, and other items should be duly considered.

The location of power house and sub-stations, of car shops, etc., requires careful consideration.

The business probably obtainable for each class of service—passenger, express, freight, mail—should be estimated on an annual basis, and also monthly. In some cases, the sale of power and light may be contemplated, but these items should be separated from receipts from railroad operation. The probable rates obtainable, the expense of operation, including financial and all charges, the total investment and the net income for the second, fifth, and tenth years of operation (or some other future periods) must be predetermined with the greatest care.

### *Modification*

The next step is to consider each general feature and then each detail of each general class and ascertain what changes could be made, and the *net* result,—*i. e., the effect on dividend.*

### *Affecting Factors*

A careful study should be made of the past history, the present development, and the tendencies of the territory; and these should be considered with reference to the probable effect on the magnitude and the character of future growth.

The rules and the apparent tendencies of the decisions of the Interstate Commission and of the Public Service Commission having jurisdiction should be investigated.

Not only should location, construction, and equipment be considered with reference to the traffic "in sight", but also with reference to the development of the territory, including the possibility of assisting in such development; and, in the latter connection, the character of construction and of equipment which will be most desirable if such development is obtained.

The history of the existing transportation companies serving the same territory should be noted, also the policies or tendencies of the officers, as, for example, whether they have fought or coöperated with other electric railroads along their lines.

### *Profit Or Loss*

*Profit or loss depends upon the difference between two almost equal amounts.*

A very small percentage of difference in receipts or expenses will make a *large* percentage difference in the amount available for dividends.

Location, including terminal facilities, will largely affect the gross income and also the cost of construction. The character of construction and equipment somewhat affects the receipts, and largely affects the operating expense, including maintenance, depreciation, and accidents.

### *Importance Of Careful Preliminary Investigation*

A slight change in location may favorably or unfavorably affect construction-cost and gross and net income, therefore, practically speaking, it is impossible to give too much time and expense to a careful preliminary investigation.

The latter will frequently indicate that, as to the *immediate future*, certain locations will cost a comparatively small amount, and that such grades as are economically advisable for the traffic immediately in sight can be constructed at slight expense, also that there will be a minimum expenditure for bridges and an avoidance of grade crossings of other railroads or of highways. It may be possible that such a location is also advisable as to the more distant future, including strategical position with reference to business competition. If the grades, bridges, and trestles can be so modified later as then to obtain a road having grades desirable for such future traffic, the location may be advisable. Probably, however, such will not be the case as to at least a portion of the route; and the future must always be considered.

### *The Future*

*Considering the future is not, however, equivalent to building for the future.* Planning for the future is advisable, but expending capital in order to provide for the distant future requires careful consideration. It might be better to place such money in a sinking fund, rather than in unproductive construction. Such sinking fund is usually a theoretical consideration. The more usual consideration is, "Can such present unnecessary expenditure be saved and the total cost reduced, and thereby the proposition be made more attractive to capital?" Steel bridges *vs.* wooden trestles are simple examples of such consideration. Future changes of grade will require (at least usually) a greater total expenditure than if the roadbed were originally constructed at such final grade, but, nevertheless, the interest saved is always important and may be vital.

Change in location is always expensive. When the road is proposed, much of the right-of-way has little value; and a skillful promotor can sometimes obtain right-of-way in a new territory for a comparatively small amount. When, however, the road develops the territory, then land becomes worth more to the owner, and is likely to cost the railroads on the basis of even a greater percentage of increase.

The general result is that, to a considerable degree, the design and more especially the construction which make provision for the future should be mainly in connection with such items as will require a far greater total expenditure when in the future the same are modified or reconstructed than if originally so constructed. Right-of-way, and especially terminal facilities, are free from maintenance and depreciation; and to change or add to them in the future is very costly. On the other hand, such items as ties, poles, trestles, minor buildings, and rolling stock, require renewal in a comparatively few years and are largely independent as to their functions. Usually they should be designed with reference to the near future; and the character of replacement should be allowed to await the development of the business.

### *System And Data Sheets*

When making a preliminary investigation of the territory, a definite plan should be followed. Doubtless all engineers who are experienced in such matters prepare data sheets on which they note such things as they consider important. It is very advisable to prepare general data sheets, tabular forms, etc., at times of comparative leisure. When a specific case is under consideration, the forms prepared are liable to be affected by special conditions and thereby lose general applicability and convenience for comparison.

The general character of information desired can be divided into two classes:

First. That which in a general way always exists. For example: division of territory into cities, towns, villages, rural, etc.; population and its tendencies; public buildings; public service properties operated by the city or by corporations; educational institutions; churches; theatres; libraries; parks; fair grounds; banks and building and loan associations; manufacturing establishments; wholesale and retail business houses; etc.

Second. Conditions of an unusual character, such as oil or gas wells, exceptionally large state institutions, manufacturing plants with worldwide reputation and having many employees, etc.

The unskilled observer, and sometimes even the skilled observer occasionally neglects to check off his list; and he obtains quite complete information relative to the unusual or striking and spectacular conditions and omits some of the items in the first class. The result is that additional money and time are required in order to obtain data, or else they are not obtained.

*Data*

When obtaining data from individuals, considerable allowance must be made. It is well known that locating the high-water mark of a stream on the basis of the statement of the "oldest inhabitant" is very unwise. Usually, information can be obtained from more than one source and the advisable discount made; and thereby fairly accurate information can be obtained as to practically all of the major non-technical factors relative to the territory. Bank statements and talks with bankers are very helpful. The country banker has a detailed knowledge of the crops, mortgages, and points to which shipments are made, and as to all of the activities of the rural communities; and his statement can be accepted as approximately accurate, especially if checked up in a few cases by the examination of farms, etc. The conditions of the fences, buildings, &c., usually indicate the facts as to mortgages.

The application of general statistics to a specific case may be helpful; but it is always accompanied by the serious danger that figures may be used which should not be applied to the case under consideration.

Statistics can be obtained as to roads in the same general territory, and possibly having the same principal terminal town; and these should be considered carefully. No statistics from any road should be applied to the proposed road, unless the engineer has quite complete knowledge as to the road from which the figures were obtained. No two roads are exactly alike, and, as before stated, it must never be forgotten that a very slight difference in the net receipts may make the difference between profit or loss to the stockholders.

## ENGINEERING TEACHING*

This is a subject concerning which the economics are difficult to define. Dr. Swain outlines them thus:

1. Engineering teaching should be done by men who have had practical experience, and also who have had some training in teaching and psychology and who are in sympathy with the point of view of young men. Moreover, and most important of all, they should be well-balanced men, and not faddists. I am inclined to think that the teaching profession, as a whole, contains more faddists and men of unbalanced views than does any other occupation; and I consider that the teacher can do more for his pupils by giving them sane and sensible points of view, methods of attack, and clear conception of the possibilities of the subject studied and its relation to other subjects, than by filling them up with technical knowledge.

2. The teacher should aim first of all to teach his students to think logically, clearly, and concisely. The great bane of teaching today is that its object, in most cases, appears to be to give information. The result is that it makes rule-of-thumb men. Many students, however, seem to think that that kind of thing is what they come to school to get; and it takes some readjustment of their point of view to make them see that what they need more than anything else is clear thinking. For this reason, what a man gets out of his college will depend more upon the teachers with whom he comes in intimate contact than upon the subjects which he studies.

3. Engineering teaching should consist of courses which are well coördinated, so that there shall be a gradual and systematic advance from one subject to another, without any more repetition than is necessary to hammer the principles in. Some amount of repetition is desirable for this purpose. One of the most difficult things is to procure the proper coördination between engineering topics taught by the engineering department, and other subjects, like mathematics, physics, etc., which are taught by other departments.

## HARBORS†

It is somewhat difficult to generalize upon the economics of harbor construction, because every harbor has its own problems to solve, depending on class and quantity of freight and shipping, of railway approaches, of climate, and of a dozen other contingencies.

It may, however, be premised that there is a solution for each individual case, and that the economic development in any case must be found in a thorough consideration of conditions. Such conditions in nearly every instance will be found to be rapidly changing with increases in size and draught of ships, necessitating longer docks and more commodious freight storage. In Canada, especially, the very great increase in ocean freights, demanded by the immense shipments of wheat from the Northwest, has

*Data furnished by Dr. Geo. F. Swain, professor of civil engineering at Harvard University, and consulting engineer, also Past President of the American Society of Civil Engineers.

†Data furnished by Col. Wm. P. Anderson, chief engineer of the Marine and Fisheries Department of Canada, and Past President of the Canadian Society of Civil Engineers.

forced in Canadian ports rapid and vast increases in harbor accommodation—instance the ports of Vancouver, Prince Rupert, Port Arthur, Fort William, Montreal, Quebec, Halifax, and St. John.

For the economical and successful development of a harbor, the first essential is a comprehensive layout of the water-front as a whole, taking advantage of all local factors, such as contour of shore, depth of water, set of current, facility of railway approach, in order to secure the best results. It may be laid down as a general rule that the best layout is to provide wharves in parallel lines, at such an angle to the quay wall as will allow easy railway approach and facilitate the entry of vessels to the docks.

In most harbors, sufficient provision has not been made in advance for progressive deepening, and much waste has ensued in consequence of the necessity of rebuilding for each increase in depth demanded by the deeper-draught vessels.

The question of building wharves of timber or of more permanent material is one that gives much thought to the engineer, and the decision must depend on many factors. With the advance in cost of timber and the cheapening of concrete processes the tendency is very general to use concrete increasingly. It is often found to be good practice from the score of economy to place timberwork cribs below low tide and finish with concrete blocks or mass-concrete.

There are many problems yet to be solved in connection with the composition and placing of concrete. Many instances have occurred of the disintegration of concrete by chemicals absorbed from salt water, and it is also a question whether reinforcement in salt water is not liable to corrosion. There is plenty of room for further study of all these problems. In my personal experience I have seen a good deal of destruction of concrete quay walls, the bad disposition of the interior filling and the frost forcing the walls out of alignment.

Sufficient consideration has in the past not been given to convenience of construction of freight sheds and to vehicle and rail approach and for handling freight. Generally, freight sheds should be so designed that machinery can be used for loading and unloading into and out of them; and so that transfer from rail to ship can be effected with the least possible handling and truckage. The best means of accomplishing such aims must, of course, vary with every shed and with every class of freight.

In modern harbors it is invariably a rule to separate rail transport from other vehicle transport and so to arrange the approaches that the one class cannot interfere with the other.

## HIGHWAYS*

Concerning the economics of highway designing and construction, the following data are taken from a letter of W. G. Harger, Esq., C. E.

The details of economic highway design are everywhere a local problem depending on the available materials, climatic conditions, and traffic requirements. I know of no one who has had enough personal experience in the design, construction, and maintenance of the various types under

*Data furnished by W. G. Harger, Esq., C. E., engineer of the Commission of Highways of New York State.

different sectional requirements to pose as an expert over any extended part of the country, except on very general lines.

The salient features which govern the cost of a highway system are legislative and finance programs which provide the necessary money at the proper time, an engineering design which at all times strives to use local materials to advantage, and a constructing staff which insists on good workmanship.

The financing of our New York State system of highways has never been well worked out for either construction or maintenance; and what applies to us, I believe, is true of a large percentage of cases. The permanent features of a highway improvement are the grading, drainage, and foundation. The surfacing is temporary, even for the so-called "permanent" types. Road improvements are generally financed by long-term bonds; and no provision is made for construction renewals before the original bonds expire. The rigid-pavement types such as brick, asphalt, concrete, etc., need resurfacing in from ten to twenty years; the macadams in from five to ten years. The ordinary maintenance for the rigid types will run about $200 per mile per year with a resurfacing charge of $10,000 to $15,000 per mile at intervals of about 15 years. The ordinary maintenance on macadams is about $500 per mile per year, with a resurfacing charge of $4,000 to $6,000 per mile at intervals of seven to eight years. The yearly cost of maintenance and renewals amounts to approximately $1,000 per mile. Provision for this amount has never been made, which circumstance results in a gradual deterioration of the roads, and will finally occasion an unnecessarily large expenditure to put the system back in good condition. Proper provision should be made for maintenance and renewal, or else a large future waste is certain to occur. A foresighted policy in this particular would save the community more than would any engineering economics of the design.

The engineering design rests on the consideration of construction, maintenance, and renewal costs. In discussing this problem most of the current literature and most highway speakers emphasize and confine economics to the selection of pavement type. This is a natural result of the exploitation of various materials and patented processes. As a matter of fact, our experience indicates that, for 75 to 80 per cent of the roads, the final cost is not greatly affected by the selection of type, except as it governs the use of local material. In general, the high and the low priced pavements cost about the same, considering interest on first cost, maintenance, and renewals. What is saved on first cost is spent on maintenance.

The engineering economics of design are limited to a careful grading and safe foundation design, utilizing local material; and to a selection of the cheapest first-cost type of pavement of the general class required by the traffic,—*i. e.*, a rigid type for very heavy traffic, and for all ordinary roads any type which will utilize local materials to their best advantage. On from 75 to 80 per cent of the mileage of most State systems, any standard type of construction which is the cheapest in first cost will generally be the cheapest in the end.

The inspection of construction has more effect on the final cost than has the design. On government work there is a great variation in the care and knowledge of the inspectors. Well-built macadams are much cheaper in the end than poorly constructed brick or concrete pavements.

The problem of improving inspection is a difficult one, and the results appear to be spasmodic. If good inspection is not reasonably certain, the more-nearly-"fool-proof" macadams are the most economical designs.

## INSPECTION*

Engineering inspection has two economic relations, first in its effect upon the work inspected, and second in the actual conduct of the inspection.

It is inevitable that errors occur in the manufacture of materials and in construction, irrespective of the question of intentional avoidance of the requirements of the specifications. The later the discovery of such errors in the progress of engineering work the more expensive is the correction, both in its own cost and in the cost of delay to the completion of the work. It is, therefore, of prime importance that the manufacture of material, the fabrication in the shops, and the erection in the field should have all errors and departures from the specifications discovered and corrected at the earliest possible moment. Competent inspection serves not only to discover and correct such errors but also to aid the contractor in avoiding them and to lead him to stronger efforts on his own part, when he is well aware that such errors are certain to be discovered and the responsibility brought back to him. Competent inspection can also frequently suggest more expeditious or economical methods of manufacture and thereby tend to economy.

The performance of inspection work has become somewhat of a specialty and requires experienced and skilled men of a number so located as to avoid, as far as may be, the expense of travel and the loss of time necessary thereto. When the manufacture of engineering materials for a contract is conducted at a number of different points, such work progresses at approximately the same time and must be inspected by a number of men; the manufacture may be intermittant, requiring more men at one time than at another; and the greatest economy is accomplished through an organization of experienced inspectors who are able to undertake the work of inspection (each at his location) for several parties at the same time. With such an organization skillfully handled, there is a minimum amount of lost time and expense in traveling, with a corresponding reduction of cost.

The processes of manufacture of material are so highly developed that large output with minimum handling and delay is essential to the successful operation of the manufacturing plant. Properly to conduct the inspection under these conditions, it is essential that the inspectors be experienced not only in the line of work but also frequently with the individual manufacturer's facilities and methods. The inspector must have full knowledge of all details of manufacture and must know by previous experience when his presence at any portion of the works is essential to the best carrying out of his inspection.

*Data furnished by P. S. Hildreth, Esq., C. E., of Hildreth & Co., inspecting engineers, New York City.

The above remarks apply particularly to important engineering structures such as bridges, steel frames of large buildings, important machinery, and the like. No branch of engineering requires more of the old-fashioned quality of common sense and tact, thoroughness, and loyalty to the work than does inspection. At best it cannot be entirely complete, nor can it replace the requirement of contracts and specifications as to the essential qualities of materials and workmanship; but it can always, if well done, be of marked economic value in connection with the work itself—and frequently to the contractor.

## MINING*

The business of mining consists in the extraction of valuable minerals from the earth with the greatest possible profit. Like Gaul it is divided into three parts.

1. Exploration or prospecting. The search for minerals.
2. Extraction of the ore from the ground.
3. Reduction of the mineral to a marketable condition.

With the exception of gold, all metals and minerals mined vary in value from time to time; and mining operations should be adjusted so that the maximum profit shall be obtained during a period of high prices. Copper, lead, zinc, and mercury were sold in 1916 at double the minimum prices of 1914. Other minerals, such as petroleum, potash, borax, and nitrates, also vary considerably in value from year to year.

### *Exploration, Prospecting, Or The Search For Minerals*

Under normal conditions, the vast majority of mineral deposits throughout the world are of too low grade to be worked profitably. Under any circumstances, owing to the fact that we cannot see into the ground, the work of prospecting and exploration is usually fruitless and carried on at a loss. It is notorious that great and successful mining corporations (mining copper, lead, or oil) spend very little of their funds on exploration work searching for minerals, except in very favorable or well-proven districts. Such companies prefer to purchase mineral deposits, even though the price is high, after their discovery by other parties. This is a better economic policy than to expend funds in a fruitless search. In any case, the proportion of money invested in exploring for mineral deposits should be very strictly limited, in order to avoid undue risks of losing the capital invested.

In some deposits, such as coal, salt, iron, and sulphur, these risks are not always so great; but, ordinarily, the costs incurred in searching for deposits of gold, silver, copper, and lead are enormous.

### *The Extraction Of Mineral From The Earth*

This problem is that of finding a method of extracting the ore at the minimum cost. It varies enormously with the size of the deposit, with its character and geographical location, with the grade of the ore, and with numerous problems of administration, such as drainage, transpor-

*Data furnished by James W. Malcolmson, Esq., M. E., consulting engineer to the Lucky Tiger-Combination Gold Mining Company, Kansas City, Mo., and Mexico.

tation, ventilation, and other factors. Where labor is high in price and fuel cheap, as in the United States and European countries, labor should be economized to the last degree; and machinery, explosives, and scientific method of transportation should be utilized to the greatest possible extent. In other countries where labor is cheap, fuel high-priced, and railroad facilities poor, a different policy must be adopted; as money may readily be lost by the use of machinery, especially if it be necessary to import skilled labor to handle the equipment. All the factors in the problem vary in every mining field; and it is only by careful study that the proper economic plan of operation can be worked out. Conditions in Joplin, Missouri, may vary so greatly from those in Clifton, Arizona, or in Alaska, that an engineer successful in one of these fields often fails utterly when transferred to another district.

The mining of ore occurring in thin seams and worth $100 or $1,000 per ton presents difficulties and economic problems very different from the mining of immense deposits of copper containing values of $6 per ton or coal worth $1 per ton. The extraction of oil at $1 per barrel or gas at 1 or 2 cents per thousand feet presents yet another class of economic problems altogether different in character, although the underlying main object is always the same—viz., to earn a profit on the investment, and the return of the capital invested before the deposit is worked out and exhausted.

It is of interest to consider to what depths mining is economically practicable.

Coal is mined in Belgium at a depth of 4,000 feet. Copper is mined in Michigan from 5,300 feet in depth, and gold is mined in the Transvaal from almost as great a depth. The problem of mining from great depths is altogether an economic one, the difficulties met, the costs of hoisting and pumping, the problems of increasing temperature and ventilation being all engineering questions for solution.

Mining of any ore-deposit is a transitory business; and, by the time the ore is exhausted, the work ceases and the mine is abandoned. The business, therefore, has special economic risks to such an extent that it is generally recognized as an extra hazardous financial operation, and is often frowned upon by so-called conservative capitalists. At the same time it can readily be demonstrated that the whole structure of our civilization rests on the mining industry. Without coal, iron, copper, and other minerals we should be back once more in the stone age.

### *Reduction Of The Mineral To A Marketable Condition*

The methods of reduction vary so materially with the different ores and the different localities where they are mined that it would be almost impracticable either to systematize them or to discuss their economics, hence the attempt will not be made. Good judgment and common sense, applied to each case as it arises, are the surest means of attaining an economic method of reducing and concentrating ores.

## RAILROADING*

The subject of the economics of modern railroading is a broad and intricate one, and deserves a full and elaborate treatment by a master hand; but, unfortunately, none of the authorities seem inclined to write an exhaustive treatise on the subject. Wellington's great work, "The Ecocomic Theory of Railway Location", is now out of date, and should be replaced by a modern book covering the entire ground.

The best that the speaker has been able to do with this subject for these lectures was to obtain a few notes on railroad economics from two of the highest American authorities; and these are presented herewith.

Mr. Holbrook writes: Safety of the road and of trains being assured so far as possible, economy is of prime importance. This is true throughout all the departments of the railroad organization. The civil engineer is especially concerned with the economics which may be attained by proper care in location, in construction, in maintenance, and in structures.

The location problem may be taken as typical.

The road must be located so as to insure that net earnings shall be as large as possible. To do this:— (1) Provide for the maximum possible income by running the line to or through all important traffic points which can reasonably be reached. (2) Provide for the smallest possible expense by so locating the line that the sum of operating expenses and fixed charges shall be a minimum. ("Operating expenses" as here used include all expenses for operation and maintenance).

The procedure recommended by Wellington, which is probably the safest and best, is to lay down first the cheapest line which will carry the traffic with safety. This will be a relatively expensive line to operate, and, probably, will not be the best (or most economical) line, but the fixed charges for interest upon the construction cost will be small. Then study this line in detail, and revise it only where the revision can be shown to be economical in itself, reducing grades and removing more or less of the curvature, distance, and rise and fall. In considering the effects of these changes upon operating expenses, it is necessary to take into account the results not only upon the cost of running trains, but also upon the cost of maintaining structures.

By reducing the ruling grade we make it possible to handle heavier trains, and therefore fewer trains are necessary. This results in a saving (which may be very large) in operating expenses.

The reduction of curvature, distance, and rise and fall is of less financial importance; but the effects are definite and of sufficient consequence to warrant most careful study of the line, section by section and part by part.

The effects of each proposed change upon construction-cost and upon operating-expenses are calculated, and the interest charge upon the increased cost of construction is compared with the annual saving in cost of operation. So for each of the proposed changes.

Other items enter into the problem, but these are the most important.

*Data furnished by Elliot Holbrook, Esq., C. E., valuation expert to the Union Pacific Railway System, and Fred Lavis, Esq., C. E., consulting engineer to the American International Corporation.

Construction and maintenance problems might be discussed similarly. Many of the problems involved are not special to railroad work, but some of them, as track, signals, etc., are not met with elsewhere.

There are certain special questions of design where, as always, economic considerations control; as, for example, in determining the proper size and weight of rail for a certain line, the proper size and material for ties, the use of special steels in track work (especially in frogs and switches), questions involving the design of signal systems, the placing of passing sidings to give the maximum capacity to the line for a given expenditure, the design of yards and terminals, etc.

Mr. Lavis writes thus: A railroad is a machine, the product of which is transportation. The type of machine which produces the finished article at lowest cost is the most economical. The total cost of transportation is composed of two principal factors, the actual cost of operation and the interest on the investment. The latter is governed, of course, by the original cost of the line and its equipment. The cost of operation is divided into four principal items: General expenses, Traffic expenses, Cost of transportation, and Cost of maintenance, the latter two being those in which the engineer is generally most interested. The Cost of transportation is affected by Distance, Curvature, Rise and fall, and Rate of ruling gradient. The cheapest line to operate between any two points is a straight line of a uniform rate of gradient, provided this latter does not exceed the reasonable limits of economical operation by adhesion locomotives.

Deviation from a straight line involves greater distance and introduces curvature, both of which increase the total resistance to be overcome by the locomotive, and, therefore, increase the cost of operation. Deviation from a uniform gradient introduces rise and fall. Within certain limits this has little effect on the cost of operation, as the saving in power on the down-grades offsets the additional power required to climb the up-grades; but beyond these limits the stored momentum in the moving train is destroyed by the use of brakes on the descending gradients, and the additional climbs are added resistance. All stops increase the cost of operation.

The rate of gradient is often of importance; and additional distance may be justified to obtain a lower rate. The value of this item depends largely on the volume and the kind of traffic; but, provided the amount of the rise and fall is the same, it is by no means always the case that a lower rate of gradient permits cheaper operation, if it involves greater distance (or even greatly increased cost of construction) to attain it.

A further item of importance involves the positive or negative values of deviation due to the necessity of reaching centres of traffic.

The costs of maintenance depend partly on the natural wear and tear due to the action of the elements, which affect in different degrees different types of structures,—that is to say, whether they are of wood, stone, or iron—and partly on the wear and tear due to the traffic passing over the line, which amount depends on the volume of the said traffic.

## SEWERAGE*

Concerning the economics of his specialty of sewerage, Harrison P. Eddy, Esq., C. E., writes as follows:

1. A fundamental economic consideration in the design and construction of sewerage works is the provision which shall be made for the future. The decision must depend upon an opinion of the rate of growth and development of the community. This opinion must be based upon a study of the many natural conditions, and of the history of other cities similarly situated, and upon a consideration of the changes likely to take place, due to the advancing age of the whole country, or the portion of the country in which the community is situated.

2. The quantity of sewage for which provision should be made, must be based not only upon present conditions, but upon a mature judgment as to future conditions, as the requirements and demands of the public are constantly changing and at present rapidly increasing. Too great an allowance for future growth results in waste. Too small an allowance will be equally disastrous.

3. Too great provision for the future may be followed by difficulties in operation, resulting in unsatisfactory conditions or excessive operating costs.

4. Provision for run-off during storms must be based not alone upon rainfall and the estimate of the corresponding run-off, but also upon the expenditure which the community can afford to make for the satisfactory removal of storm water. It may well be that some communities can better afford to be flooded occasionally, and even to pay damages from the public treasury on account of such flooding, than to go to very large expense in order to avoid such occasional difficulties.

5. In sewage treatment, economic considerations should play as important a part as in sewerage and drainage; perhaps even a greater part. Here it is necessary to balance the advantages obtained against the cost. The engineer should not be misled by æsthetic considerations which may lead him to the conclusion that absolutely no sewage and no partially treated sewage should be admitted to natural water courses. The expense involved in attaining such an end may be entirely out of proportion to the resulting advantages.

6. It is important to distinguish between conditions which are known to be detrimental to public health, and those which are simply objectionable on æsthetic grounds. A reasonable expenditure for the protection of the public health should always be advocated. Nevertheless, such expenditures should be balanced, and the funds available should be expended upon those enterprises which will produce the greatest results. For example, by a complete treatment of the sewage of a municipality, the possibility of contracting typhoid by a few bathers, or a few persons enjoying the water-way for pleasure purposes—such as boating—may be avoided. A similar expenditure in contagious-diseases hospitals, in the fight against tuberculosis, or in a number of other ways, may result in a saving of many times the amount of sickness and death which might be

*Data furnished by Messrs. Metcalf and Eddy, consulting engineers, Boston, Mass.

caused by allowing the untreated sewage to be discharged into the neighboring water course.

7. It is important to preserve our natural resources. Every stream or body of water has an economic value to the community. If sewage is allowed to be discharged into such waters, in amounts which shall deprive us of their use, we suffer an economic loss. It is, therefore, important to measure these values and balance them with the cost of treating the sewage to an extent necessary to maintain these natural resources in a condition which shall enable us to take advantage of their values. In some cases, it will prove economical to abandon the natural resources to the disposal of sewage and industrial wastes. In other cases, treatment necessary to preserve the waters in suitable condition for our use and enjoyment will involve expense much less than the value of the waters.

8. In industrial communities where liquid wastes must be disposed of, other economic questions are introduced, such as the value of the industries to the communities in question, and the expense which may be required of the industries, in the treatment of their wastes, without the danger of driving them out of the community. As in the case of sewage disposal, the value of the water-ways to the community must be off-set against the cost of the treatment of the industrial wastes; and coupled with this balance must be weighed the value of the industry to the community.

### WATER SUPPLY*

On this subject Alfred D. Flinn, Esq., C. E., writes as follows:

> Replying to your letter of November 8, I am jotting down below several more or less random questions which occur in considering the economics of water works. I have been unable to find time to attempt to classify them or even to make the list at all complete. They are merely suggestions which have occurred off-hand, and might be described as "Some Examples of Problems Arising in Various Places and under Various Circumstances in Connection with the Economics of Water Works Projects".
>
> Possible extension of system with growth of community and provisions therefor; relative cost of each.
>
> Pumping from wells *versus* supply from stream or lake by gravity.
>
> Pumping from a nearby source *versus* gravity supply from a distant source.
>
> Air-lift *versus* centrifugal well pumps.
>
> Reciprocating pumping engines *versus* turbine pumps, including cost of buildings and foundations.
>
> Filtration of a nearby impure supply *versus* a more distant supply of water of better natural quality.
>
> A comparatively lower-cost supply of hard water *versus* a more expensive soft water, including expenditure by members of the community for soap, boiler compounds, etc.

*Data furnished by Alfred D. Flinn, Esq., C. E., deputy chief engineer of the Board of Water Supply, New York City.

Relative suitability and economy of cast-iron, riveted-steel, welded-steel, and wooden pipes, depending upon sizes, prices, feasibility of transportation, life, cost of repairs, and local conditions of water, soil, climate, and electrolysis. Economic sizes of pipes, considering probable increase of consumption.

For large steel conduits, jacketing with concrete and lining with cement mortar, thus greatly prolonging life and materially increasing the hydraulic capacity, compared with ordinary coatings and the roughness due to rivet heads, laps at joints, and tuberculation.

Should very large steel pipes be shipped from the shop completely formed and coated, or the plates rolled to the proper radius and nested, to be riveted together in the field and there protected by concrete and mortar or coated?

Should filters be of the slow-sand type or the rapid-sand type? What rate of filtration should be adopted? If rapid filters, what coagulant? How large should the individual filter beds be, and how should they be grouped?

What building materials should be used for pumping stations, gate-houses, and other buildings?

Should watersheds be owned outright and sources of pollution removed, or should inexpensive patrols be maintained to prevent the worst cases, and dependence be put upon the purification of the water by filters?

Can the watershed selected as the source of supply be best developed by one very large reservoir or by several smaller reservoirs?

For aqueducts or large pipes, would a straighter and shorter line, with tunnels and deep cuts, be cheaper than a longer line of relatively light cut-and-cover construction, with few or no tunnels?

Should bottoms and slopes of impounding reservoirs be stripped of vegetation and soil at considerable expense, or should the money be expended for aeration and filtration?

## CONCLUSION

The speaker recognizes clearly the numerous faults and deficiencies of his entire treatment of the subject of "Engineering Economics" in this series of lectures; but he feels that he has done his best, considering all the circumstances and the governing conditions. His hope is that this effort will be the means of inducing other technical writers to elaborate upon the subject and thus place at the disposal of all students of engineering and all practicing engineers a vast fund of information upon the main general underlying principle which should nearly always govern in the conception, designing, and construction of all important engineering work—ECONOMICS.

It may be of interest to state that for the last eighteen months the speaker has been acting as Chairman of the Committee on "The Study of Economics in Technical Schools" in the Society for the Promotion of Engineering Education; and that he and his co-laborers have been studying the question carefully, to the end that they may be able, at the next annual meeting of the society, to present a report thereon which will be of real value, and which, it is hoped, will be the means of establishing the study of economics in all the first-class technical schools of this country upon a sound, logical basis.

It is the earnest wish of the speaker that the work of that committee, combined with the effect of these three lectures, will result in the publication of an exhaustive standard treatise on "The Economics of Engineering", prepared by the labor of a large group of prominent American engineers, selected from all lines of technical activity.